Thesis/
Reports
Shields, D.J.

THE ENERGY AND MINERAL SUPPLY AND DEMAND SITUATION THROUGH 2045

The Energy & Mineral Supply and Demand Situation Through 2045

Susan Major

12/10/02 12:21 PM

To: Deborah Shields/RMRS/USDAFS, Dorothy L Martinez/RMRS/USDAFS,
cc:
cc: Susan Major/RMRS/USDAFS@FSNOTES
Subject: Re: Invoices to Be Returned to Cooperators Today on Agreements RMRS-98121-RJVA and 02-JV-11221611-244

Final Report for RMRS-98-121-RJVA

Thanks Deb. I will process both invoices.

Sue

Sue Major
Clerk, Grants & Agreements
970-498-1395
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Deborah Shields

Deborah Shields

12/06/02 02:05 PM

To: Susan Major/RMRS/USDAFS@FSNOTES
cc:
Subject: Re: Invoices to Be Returned to Cooperators Today on Agreements RMRS-98121-RJVA and 02-JV-11221611-244

Hi Sue,
The 'report' of 98121 is text and tables. I am attaching electronic copies the text for your records. this is what we asked for and it was supplied. The work plan has been created for the SMR which is the task under 244. Both can be paid.

Thanks,
Deb

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[redacted] assess.doc [redacted] ExecSummary.doc [redacted] Section II.doc [redacted] Section III.doc

Susan Major

Susan Major

12/06/02 12:53 PM

To: Deborah Shields/RMRS/USDAFS, Dorothy L Martinez/RMRS/USDAFS
cc: Susan Major/RMRS/USDAFS
Subject: Invoices to Be Returned to Cooperators Today on Agreements RMRS-98121-RJVA and 02-JV-11221611-244

I was just following up one last time before I return the following invoices. I plan to return these invoices to the Cooperators today.

Did we receive the following reports? If so, please let me know asap.

RMRS-98121-RJVA
Colorado School of Mines
Dr. Wade E. Martin and Dr. Ingrid M. Martin
"Human Dimensions of ecosystem Management"
FINAL REPORT DUE 9/30/02 (If received, we will need two copies sent to us.)

02-JV-11221611-244
The University of Nevada, Reno
Dr. Dirk VanZyl
"Mineral Indicators of Sustainability"
WORK PLAN DUE 9/1/02

Thanks for your quick reply.

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THE ENERGY AND MINERAL SUPPLY AND DEMAND SITUATION THROUGH 2045

Minerals Technical Document in Support of the Resource Planning

Act Assessment

Deborah J. Shields, Editor

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USDA Forest Service

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Fort Collins CO 80526

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NATURE OF EXHAUSTIBLE RESOURCES

Virtually every energy and minerals related subject is informed by the physical and technological characteristics of these resources and the economic realities of the extractive industries. The land management implications of past, current, and future production are a direct consequence of the fundamental nature of the resources and industry. This section of the Minerals Technical Document provides an introduction to exhaustible resources. First, the different types of mineral and energy resources are briefly described. Next, the basic characteristics of the extractive industries are introduced. The chapter concludes with discussions of nonrenewable resource supply and demand concepts.

Categories of Mineral and Energy Resources

Energy and mineral materials become resources when two basic conditions have been satisfied: there is a demand for the services provided by the material; and the knowledge and technical skill exist to allow its extraction and utilization. (Zimmerman 1951). Resources become reserves when they can be economically produced given currently technology, costs, and prices. This distinction is extremely important and will be discussed at considerable length in the section on energy and mineral supply.

Mineral Resources

The term "minerals" encompasses a broad spectrum of elements or combinations thereof. Minerals are naturally occurring, homogeneous substances that have been formed by inorganic processes. Each possesses characteristic physical properties, a definite and limited range of chemical composition, and a molecular structure that is usually expressed in crystalline form.

Minerals can be categorized according to their physical attributes and uses (Table IIAi-1). Starting in prehistory,

interest has focussed on the metals, which are characterized by their distinctive luster, malleability, ductility, thermal and electrical conductivity, and ability to form positive ions. In particular, humans have treasured the precious, or noble metals (gold, platinum group metals, and silver), for their beauty, rarity, and nonreactive properties. Even in modern times precious metals are highly sought after.

The remaining metals can be subdivided into several groups. In medieval times, all non-noble metals were referred to as base metals. That term is now reserved for a specific group of 7 elements, including copper, lead, and zinc, that are somewhat more chemically active than are precious metals. Ferrous metals are those used in combination with iron, usually to produce steel. Light metals, such as aluminum and titanium, have lower atomic numbers and hence lower specific gravity than do the base or ferrous metals. Metallic minerals in the Lanthanide series of the Period Table are termed rare earth elements, or rare earth oxides, reflecting their common chemical form.

Deposits of pure, or native, metal are seldom found in nature. More typically, a metal will occur in one of several types of mineralogic compound. They are seldom traded at this raw stage, however. Instead, milling, smelting and refining are utilized to separate the metal of interest from other elements and compounds present in the ore. The metals are then sold in pure or near pure form, with any unit replaceable by and identical to any other, regardless of origin. Such commodities are termed fungible, and when traded in organized international markets, each unit sells for the same price (transportation costs aside).

The nonmetallic minerals comprise numerous crystalline compounds[1], such as limestone and feldspar, as well as a few elements, such as sulfur, and the noble gases. Removal of one or more of the constituent elements via smelting or refining, in some cases would result in loss of the inherent properties of the mineral (for those occurring in crystalline form). For example, common limestones and high quality marbles are both calcium carbonate compounds, but reducing them to discrete elemental form would destroy their character as stones.

Nonmetallic minerals tend to be classified by their uses and hence are termed industrial minerals. Feldspar, for example is classified as a ceramic material because it is used to make vitreous china. Phosphate is classified as a fertilizer

[1] Nonmetallic minerals have acid rather than basic properties and are incapable of forming monatomic cations. They accept or share electrons readily and thus tend to form compounds.

mineral due to its importance as a plant nutrient. Sodium, which is actually a metal, is classified as an industrial mineral since it is never found in metallic form in nature.

Nonmetallic minerals are not traded as fungible commodities because output from different sources may not have identical chemical form. Typically these minerals occur in a variety of basically similar compounds, any of which can be utilized in industrial applications if appropriate chemical or engineering process modifications are made. Many different grades and qualities of phosphate rock[2] are offered for sale, for example. The units are not identical or exactly interchangeable, but virtually all types of phosphate rock can be and are utilized to produce fertilizers. The result of this tendency to uniqueness is that the price of any unit of a nonmetallic mineral reflects its desirability relative to other similar units being offered for sale.

Energy Resources

The energy materials group comprises solid, liquid and gaseous hydrocarbon compounds, nuclear materials, and geothermal resources[3]. All these resources are utilized for heat and energy production; however, the unique characteristics of each make direct comparisons difficult. One frequently selected common denominator is heat content, or the potential thermal energy available in a fuel's heat content. A commonly used unit, and the one selected for this report, is the British Thermal Unit (Btu), which is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit.

The heat content of one barrel of domestically produced crude oil is approximately 5.8 million Btu's (USDOE, EIA 1993). The average heat content of a cubic foot of dry, domestically produced natural gas is 1,031 Btu's. A short

[2] Phosphorous is traded as phosphate rock, which is beneficiated ore. Grade refers to the content of P_2O_5 in the rock, and quality to the presence of impurities such as aluminum.

[3] Nuclear and geothermal energy resources are not addressed in this Assessment. They will be considered fully in the 1998 Assessment.

ton of domestic coal contains about 21.7 million Btu's. Although these values are widely reported, their use presents drawbacks. Firstly, Btu comparison between fossil fuels and either nuclear or geothermal energy is not straightforward. Secondly, a million Btu's is not a particularly meaningful descriptor for most people. (Think of it as equivalent to 8 gallons of gasoline). Nonetheless, the Btu is the most widely used simple measure of comparison among energy sources and Btu values will appear regularly in the energy resource sections of this report.

Hydrocarbons are formed by the slow decomposition and chemical conversion of large quantities of organic materials. Natural gas and petroleum are, respectively, gaseous and liquid mixtures of hydrocarbons, whereas coal is a solid organic material.

Natural gas is composed of hydrocarbon compounds in the paraffin series. This group includes such common products as methane, butane, and pentane. Gas may be co-produced with crude oil, in which case it is termed associated. If natural gas is produced in isolation, it is labeled nonassociated. Since most of the compounds in the paraffin series exist as gases at normal surface temperatures, they must be contained or they will dissipate in the atmosphere. As a result, natural gas does not need to be pumped; it flows freely from the well head. It is transported either by pipeline or tanker. International trade in natural gas continues to be constrained by this necessity of transport under pressure. In fields where access to a pipeline is unavailable, associated gas is often flared; nonassociated gas wells may be capped until pipeline access is available.

Petroleum, sometimes called crude oil, is made up of a closely related series of hydrocarbon compounds that range from light gases, such as methane, to heavy solids, such as tar. The chemical composition of crude oil can vary. Oils that contain sulfur are termed sour; those with little sulfur content are termed sweet. Physical properties, such as A.P.I. gravity[4] and color, can vary as well. Crude oil is traded internationally, with price depending on physical and chemical characteristics. Lighter grade oils, those with a lower A.P.I. gravity, command a higher price because they contain a higher percentage of the more desirable hydrocarbon compounds.

Coals are classified according to rank, grade and type. Rank refers to the amount of fixed carbon present in the coal. Lignite B contains approximately 25 % carbon, whereas Meta-Anthracite is over 95 % carbon. Most of the coal

[4] The A.P.I. gravity of crude oil is based on the American Petroleum Institute (A.P.I.) scale, in which pure water has been arbitrarily assigned a gravity of 10 (Frick 1962). Most crude oils have an A.P.I. gravity between 5 and 30.

produced in the United States falls between these extremes. Grade of coal refers to the presence of impurities such as ash and sulfur. Type refers to the source materials. The uses to which different coals are put reflect these characteristics, as do their prices. Coal is traded worldwide and the U.S. is a net exporter.

Indicator Resources

The nonrenewable resources reported upon here include metals, nonmetallic minerals, and hydrocarbons. Rather than consider every possible resource, this report focuses in depth on a limited number of "indicator" energy and mineral resources (Table IIAi-2). One or more of the following criteria were utilized in their selection. "Indicator" resources typically exhibit physical or economic attributes that are representative of other minerals in their class. They tend to be important economically, with large deposits in the United States. Their extraction, past or present, may have significant impacts on environmental quality. And finally, a number of the "indicator" resources were chosen because their geographic location or extraction technology could have important implications for the management of National Forest System lands.

Characteristics of Energy and Mineral Resources and the Extractive Industries

In this section the defining features of nonrenewable resources and the extractive industries are introduced. The first and most important characteristic of energy and mineral resources is nonrenewability. While some metals can be recycled, all energy and mineral resources are ultimately finite in quantity. The result is that extraction has both immediate and intertemporal consequences for both industry and society. Nonrenewability raises a very direct problem for the extractive industry. The firm will inexorably put itself out of business by doing business, unless reserves are replaced through successful exploration or the purchase of reserves previously discovered by others. But exploration is by its nature a difficult endeavor. Initially, the location of subsurface deposits must be inferred from limited information, including seismic, geochemical, and geophysical data. Core and exploratory drilling may follow. While the firm obviously expends the most effort at those locations showing the greatest likelihood of success, discovery is far from guaranteed.

Exploration activity tends to be cyclic, particularly in cases where the activity is funded out of current profits. Resource firms are more likely to undertake exploration when resources and reserves are scarce and prices are high. Unfortunately, resources prices are volatile. Various market forces could push the price down, i.e., successful exploration resulting in large additions to the reserve base. If prices drop, there may not be sufficient revenues to continue the exploration program.

The firm's willingness to undertake exploration reflects, among other things, its level of risk aversion[5]. Independent exploration firms, junior mining companies, and wildcat drillers tend to have a greater tolerance for risk than is found in either larger resource firms or the average manufacturing firm. Were this not the case, there probably would be less exploration. These smaller groups often discover new resources and then collaborate with, or sell out to, larger corporate entities when the development stage is reached.

To compensate for inevitable exhaustion of reserves, firms also seek to seek to earn a return greater than break-even . The firm seeks to maximize returns[6] by selecting an extraction path for the deposit, such that in each time period, net returns equal the return available on other equally risky investments. This concept, which Hartwick (1989) refers to as zero profit arbitration between time periods, reflects the view of minerals as a form of capital. It also exemplifies the need for dynamic, or intertemporal, decision making with regard to nonrenewable resources. The firm's desire to earn a return comparable to that available from other investments in the market may lead to changes in the rate of extraction if the interest rate varies. Assuming the mineral project is already developed, the firm will want to increase the extraction rate when alternative investments are earning a return exceeding that available from the mineral resource. Revenues can then be reinvested at the alternative higher rate as soon as possible. Conversely, if the value of the stock in the ground is increasing at a rate faster than that being paid to other investments, the firm would logically prefer to delay extraction as long as possible.

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[5] The nature of risks faced by the energy and minerals industries are discussed in more detail later in this section.

[6] According resource economic theory, the firm acts to maximize the amount of rent captured rather than total returns.

Nonrenewability can alternatively be viewed from a societal perspective. Its consequence, depletion of stocks, has been of continuing interest and concern to governments and economists. Jevons (1906) considered the possibility of coal depletion in the 1860's. In this century, Limits to Growth raised the specter of global resource exhaustion (Meadows et al. 1972). Concerns next focused on the (artificial) shortage of oil during the OPEC led embargo of the early 1970's. More recently, increased environmental awareness and the Bruntland Commission report have once again brought the issue to the fore (World Commission on Environment and Development 1987). The current emphasis in public debate upon intergenerational equity and sustainability reflect concerns about finite resources.

Reconciling the reality of depletion with a desire for intergenerational equity is complex. One approach is based on the previously mentioned idea that minerals are an alternative form of capital. Wealth is defined as accumulated human and physical capital; so, if minerals are defined as capital they can then be considered a form of endowed wealth. It has been argued that this wealth will be dissipated when a finite stock asset is extracted, unless the Hotelling rent is reinvested in another form of reproducible capital asset, such as machinery. (The portion of revenue in excess of marginal cost that is earned by the finite resource due to increasing scarcity is termed Hotelling rent.) If reinvestments are made, constant consumption, or increasing consumption in the presence of technological advancement, is theoretically possible. This is called the Hartwick Rule and has been interpreted to mean that sustainable consumption represents the use of interest earned by a continuously maintained stock of "capital" (Solow 1986). Many questions regarding this theory and its practical application remain unanswered, e.g., how substitutable is physical capital for mineral resources.

The second important characteristic of energy and mineral resources is variability. Deposits and reservoirs differ in character and geographic location. The features of quality, volume, depth, ease of extraction and nearness to markets combine to make some more costly to produce than others. Revenues generated by a marginal deposit will barely cover extraction costs. Inframarginal deposits, those with lower overall costs, earn a positive return. This return to the resource due to its intrinsic nature is termed Ricardian, or differential, rent.

Mineral taxation schemes in many countries are designed to capture some or all of differential rent. For example, the USDI Bureau of Land Management sets specific minimum reserve bids for each auction of coal leases on public lands. Potential lessors competing for the right to extract the resource offer to pay an up-front bonus, in addition to annual surface rental and royalties. The successful bidder must offer an amount at least equal to the predetermined minimum.

The goal is to set the reserve bid at a level that will assure payment to the government of at least part of the Ricardian rents generated during extraction of the coal resource.

In addition to variation among energy and mineral deposits, there is frequently significant variation within any given deposit. For nonenergy minerals, the ratio of desired material to all constituents in rock is termed "grade." Rock in place becomes ore when the concentration of the desired constituent is high enough for it to be extracted, processed, and sold at a profit. The boundary within which mineralized rock is deemed to be ore is specified by the cut-off grade, i.e., the firm cuts off extraction prior to removing any material of a lower grade. Lower cut-off grade means that more material will have to be extracted and processed to produce the same amount of product.

In market economies, ore has an economic definition; changing economics for the industry can and will change cut-off grade. If the market price for the resource changes, the quality of material that can be produced at a profit changes and reserves change as well. High enough prices may change a previously unattractive, lower grade resource into an economic one, leading to development. Decreasing market prices may have the opposite consequence. The firm may no longer be able to break-even by extracting ore at the previous cut-off grade. A choice must then be made among high grading (taking pockets of better quality ore), shutting down, or continuing to produce while absorbing losses. Given the high costs associated with shut-down and restart for many types of mineral operations, firms often choose the latter course, at least for the short term (Evans 1984). If price does not rise over time, lesser quality ores within the deposit will not be extracted which would lead to economic depletion prior to physical depletion.

The issue of when rock becomes ore and when it can be economically extracted is further complicated by technological change. Advances in exploration technology increase success in locating previously unidentified resources. Improvements in the efficacy of extraction and beneficiation processes may increase recoveries to such a degree that the low grade materials previously ignored become desirable, economic ore. When this happens, cut-off grades can be greatly decreased. For example, development of solution mining techniques has resulted in profitable reprocessing of materials previously classified as wastes and the reclassification of some disseminated metallic occurrences as economic deposits.

Of course, technological changes can also lead to either decreases or increases in demand for a mineral resource, thus impacting its price. For example, the price of platinum drops after every announcement of a breakthrough in catalytic converter technology (Raghavan 1992). However, no technological advance has actually been introduced that eliminates

the need for platinum in these devices, so to date price has always returned to previously attained levels.

There are, however, limits to price movement. A backstop technology is a supply that becomes available as a substitute for a resource that is being depleted (Nordhaus 1973). A backstop has the effect of placing an upper limit, called the choke price, on a resource. Oil from oil shale is an excellent example. The market price for crude petroleum is unlikely to rise above $60/bbl since oil shale becomes a competitive supplier at that (or a somewhat lower) price. The implication is that, in the absence of technological change, no resource more expensive to produce than the current backstop will be viewed as a reserve.

The third defining characteristic is risk. The energy and minerals industries are widely viewed as inherently risky businesses. These industries face several discrete types of risk. It has previously been mentioned that the likelihood of success in any exploration activity is uncertain. This reflects a combination of the probability that a mineral deposit exists combined with the probability that it will be found (Newendorp 1975). Even after a deposit has been identified, its full dimensions remain unknown, even during extraction, because the cost of acquiring complete knowledge prior to extraction would be prohibitive. The resource will be developed based on probability estimates of size, grade, etc. Risk is also introduced when property rights are not fully allocated, as is the case with seabed resources.

Add to this the variability of markets. Historically, mineral prices have been volatile, moving higher and lower in sometimes rapid succession for reasons both understandable and inexplicable (Slade 1989). Numerous unforseen events could drive price down: a large discovery, sales from a stockpile, or a change in demand. As we have noted, any of these could make a previously economic project unprofitable. Further, the industry is faced with the necessity of large, lumpy investments and long lead times. A large mining project could realistically require investment of $500,000,000 over a 10 year period before production (Fantel et al. 1988). A wildcat well could easily cost $1,000,000 or more to drill and then turn out to be dry. Simply put, the firm must invest large sums of money, over long periods of time, with no guarantee of payback. There may also be competition between firms over the amount and timing of new investment (Gilbert and Harris 1984). Responses to these forms of risk vary: hedging in resource markets, increased hurdle rates (desired internal rate of return), and shortened payback period.

There is some question as to whether the minerals industry is actually more risky than other forms of business activities. Certainly, other industries face many of the aforementioned risks, particularly those which are market oriented.

Nonetheless, minerals are unique in that they are finite and exhaustible, so that actions and decisions have irreversible dynamic consequences. In Lasserre's (1991) view, the most compelling argument for viewing the minerals industry as inherently more risky than other businesses is that suboptimal extraction is irreversible, whereas erroneous capital accumulation can be corrected (if at a price). Suboptimal extraction can be viewed in several ways. Resources may not be efficiently allocated intertemporally. This is more likely to be the case in the absence of fully functioning forward markets; the firm does not have perfect foresight about mineral prices and market. Conversely, extraction may be conducted in such a way that the total amount of the resource available for recovery is lessened. The latter problem is sometimes the result of the aforementioned high grading which is a reaction to price volatility.

Resource Supply and Demand

The total amount of any mineral[7] is unknown and unknowable, both because deposits of these resources are usually hidden from view beneath the surface of the earth and because, at the level of crustal abundance, many minerals are ubiquitous. (Many minerals are thought to be present on other planets, but again amounts are unknown.) Mineral supplies can be considered both in terms of this ultimate finite geologic stock of the resources known or thought to exist and of the flow of useful commodities produced from these stocks.

Unlike supply from renewable resources or manufacturing processes, the specter of exhaustion obliges attention to more than production capabilities. Measures of the geologic stock of a resource reflect judgements about what could be made available for future use. Flow measures indicate what was actually realized or used in specific periods. The purpose of this section is to provide a backdrop for the remainder of the report, particularly the commodity chapters, by clarifying the meaning and limitations of the various concepts used to characterize the supply of individual mineral commodities.

Mineral Resource Stocks

[7] The term mineral is used in this section to represent both minerals and energy materials.

Understanding the geologic stock of resources for a particular mineral is complicated by several conditions. First, a hierarchy of terms is used to describe what exists. In the case of non-energy resources, the total physical quantity of an element found in the earth's crust, sometimes called the resource base, is extremely large. That total provides little insight into mineral supplies since most of it is too inaccessible and too difficult to process. A more useful depiction of the geologic stock of both energy and nonenergy resources is provided by the McKelvey box, Figure IIaii-1.

The term resources encompasses all of the material above the bottom tier in Figure IIaii-1. Resources refer to all known, inferred, or probable occurrences of a mineral commodity that could be exploited under a prescribed set of economic conditions using technology available or expected. Resources range from geologically well defined mineralization (e.g., measured resources) to those simply speculated to exist.

Reserves include only the economically recoverable part of the geologically well defined resource (upper left corner of Figure IIaii-1). A recovery factor is applied to account for losses in extraction and processing. An economic threshold is invoked to limit quantities to those for which mining costs can be covered under prevailing conditions. Reserve base expands reserves by adding material that is technically recoverable, but at a cost above that which can be justified by current market conditions. These and other descriptive variants (demonstrated, identified, indicated, inferred, proven, probable, etc.) are used to guide assessment of mineral resources. A copy of the classification system, along with detailed definitions, appears in Appendix A. The main point is that three dimensions go into defining mineral resources; degree of confidence in the geologic information, technical possibility of extraction, and the economic feasibility of recovery.

The term reserve suggests a definite amount of a mineral known to exist. But reserve estimates are contingent on numerous variables which allow for incongruities and call for frequent revisions. In part, estimates are dependent on judgements that change, often for less than obvious reasons. Differences in individual interpretation are unavoidable when they are applied to various parts of the resource of a mineral. More significant though is the fact that the factors defining reserves are constantly changing. These factors include unfolding geologic knowledge, technological progress and changing social and economic circumstances.

Geologic uncertainty derives from the fact the inventories of deposits are subject to estimation error. As

previously noted, mineral resources tend to be incompletely delineated because exploration is not costless. Exploration takes time and results at any point are unpredictable. Further, though minerals occur throughout the earth's crust and oceans, deposits sufficiently rich to be economically exploitable are rare. Discoveries can represent large additions. The accumulation of geologic knowledge thus serves to expand both resource and reserve base estimates in discrete jumps over time. Consequently, the information on their size and quality is probabilistic in nature and subject to revision as exploration, development, and extraction proceeds.

Technical, market, environmental, and political factors (all combined in the economic dimension of Figure IIAii-1) alter the size of the reserve component over time. Improved recovery technology, for example leaching, has made possible the extraction of mineral commodities from progressively lower grade ores and horizontal drilling has increased access to petroleum resources. Conversely, deteriorating markets or price can move economic material into the subeconomic category.

Conflicting land uses, distance, or inadequate transportation capacity can render otherwise attractive resources irrelevant or unaccessible. In some cases, additional costs may be required to meet environmental standards. There may be multiple land use demands for the same area and polarization of different interests do sometimes discourage or block development of geologically, economically and technically attractive deposits. The circumstances described above mean that the most socially relevant measure of mineral resources available for future use differs from site to site and changes over time.

Mineral Commodity Flows

Resource stock measures do not lend themselves to direct comparison to mineral commodity demand. True supply curves address behavioral responses by producers to changes in demand conditions, production above or below capacity, and define supply in terms of marginal (economic) cost measures. Market structure conditions are incorporated. To study more immediate as well as long term mineral commodity supply flows, analysts often resort to measures like capacity, production, inventory, and trade data.

Interpretation of these measures can be confusing because mining is a multi-stage extractive industry. Minerals

are taken out of the earth through various underground or open-pit mining methods or through drilling and pumping. If the material is not consumed in the form in which it is extracted from the ground, it is usually concentrated to improve the mineral content or scrubbed to remove impurities. Milled concentrate is shipped to smelters and refineries where energy intensive methods are used to attain a pure metal product. These products then go to fabrication facilities where further attenuation of material occurs. Scrubbed coal is shipped directly to power plants, but oil would be transported to a refinery for further processing. Capacity, production, inventory, and trade measures often are reported for more than one of these stages, so careful attention must be paid to product form when interpreting these measures.

Annual capacity is not really a flow measure, but it is often used as a surrogate for production. It does provide insight into the boundaries on industry supply behavior because it accounts for constraints imposed by physical and engineering characteristics. Also, related information such as quality and quantity of reserves, costs of energy, materials, labor, and transportation parameters are partial determinants of supply behavior. In effect, capacity measures provide an annual equivalent to total availability measures.

Though large fixed costs add pressure to running at capacity, mineral operations do run well below or even somewhat above design rates without exceeding the minimum variable unit cost point. For example, the amount of labor used at a mine will be nearly proportional to the tons of ore moved, in contrast to a mill where a piece of equipment requires a minimum amount of labor regardless of the throughput. Operations geared to shut downs at regular intervals or for portions of the year (e.g., due to harsh climate or the requirements stemming from field unitization) can suspend operations for market reasons also. Despite apparent rigidities, mineral operations do vary output rates. Consequently, capacity measures are an imperfect indicator of future production flows.

Past production data offer several kinds of information useful in interpreting mineral supply. Comparison of annual totals with reserve estimates suggest the duration of current resource inventories. Together with trade statistics, distribution of production compared to the distribution of reserves helps pin-point where resource choke points are most likely. Production series offer some of the raw data needed for efforts to discern long term industry response patterns. Over time they reflect the collective interaction of producing units in market transactions.

However, situations important to understanding mineral sectors limit the value of historic production measures as supply proxies. Past production information is only appropriate to evaluating supplies in conditions that have prevailed

before. Discoveries, innovation, changes in regulatory climate and a host of other factors can alter historical correlations. Contingency analysis also often depends on formulations that allow response patterns not observed previously. In addition to capturing the performance of mineral producers, such formulations must also account for other sources of mineral commodities. Besides technical and economic factors, other influences can play a significant role in the flow of mineral supplies from resources.

Many minerals do not come from a rich diversity of sources, though all countries conduct some kind of mining. Almost all have sand and gravel and stone production, for example. This is because suitable deposits of stone exists everywhere and because the high weight to low-value ratio and the large volume consumption rates make long distance shipments of these materials prohibitive. Metal deposits, on the other hand, are relatively rare. For most metal commodities, ten producers usually account for more than 75% of production. Similarly, the number of major oil producing regions is relatively small.

International trade plays a large part in the supply of many mineral commodities. World consumption of minerals has always depended on international trade. A large percentage of mineral commodities are consumed by industrialized nations like the United States, Japan, the European Community, and the U.S.S.R., although all countries are to some degree dependent on the import of minerals. Many of the minerals used by industrialized societies are imported from developing nations, some with fragile economies and unstable governments. For many countries, the production of minerals is a driving force in their nation's economy. Mining, and oil and gas production, provide employment for citizens, revenue to the state in the form of taxes and, for those countries which are major traders in materials, provides a valuable source of hard currency. Some countries have encouraged investment of foreign capital with favorable tax laws and assurances of repatriation of profits and capital and security of land tenure. However, political or social unrest can undermine these promises. Some countries have imposed strict controls and even expropriated mining properties.

Dependence on foreign sources for minerals is a concern heightened during periods of rising international hostilities or embargo threats. A nagging concern is that the flow of important raw or processed materials[8] will halt at a time of critical need. One of the ways the United States dealt with this problem was by establishing the National Defense

[8] These commodities are often referred to as strategic (they are not mined domestically) and critical (they have significant military/industrial applications.

Stockpile (NDS) after World War II. The NDS objectives contain tonnages for 65 mineral materials. In recent times, goals for many commodities have been revised downward and tonnages in excess of new goals have been sold off. The United States also maintains a Strategic Petroleum Reserve.

Another way the United States dealt with potentially unstable mineral supplies is to inventory potential domestic deposits of important minerals, especially on Federal lands. The difficulty with this strategy is that though cost may be less of an obstacle to production during a time of extreme need, long lead times to explore and develop mineral operations cannot be ignored.

In summary, gauging future mineral supplies depends on integrating information from a variety of measures. Neither available stock or flow measures alone produces a full picture of mineral supply potential.

Demand

Demand is defined by economists as the amount of a good or service that an individual is willing and able to purchase at each price. Demand depends on the price of the good itself and the price of other goods, tastes and preferences, and income. Consumers are usually interested in products containing minerals, rather than minerals themselves and so demand for nonrenewable resources is derived from the demand for something else. Change in the demand for the final product changes demand for the resources needed to produce it. Obviously, this is a two-edged sword. Increased home construction and sales could lead to increased demand for titanium pigment, the ingredient that makes paint white (Lynd 1980). On the other hand, the current virtual moratorium in this country on construction of nuclear power plants has severely limited demand for uranium, from which nuclear fuel is made. As a result, the market price for uranium is low and much less is produced than was the case 20 years ago (Mining Journal 1990).

Demand for minerals is actually demand for an input to the production process. According to economic theory, a firm hires an input (capital, labor, or natural resources) until the cost of an additional ton or barrel equals the revenue that can be earned from the sale of the output manufactured with that unit. In other words, the firm will not purchase inputs that generate less revenue than they cost. Quantity demanded is thus a function of the marginal, or incremental, revenue generated by the resource input. This is an inverse relationship, with higher input costs implying that a smaller amount

will be used. A change in the price of the final product could cause a change in the fundamental relationship, as could a change in technology affecting the manufacturing process (Campbell 1985). This latter issue is of particular importance in long range forecasting of mineral demand and will be considered in more depth later. The issue of substitution between renewable and nonrenewable resources in manufacturing processes, and between energy source is addressed in more detail at the end of this section on demand.

Demand for minerals can be modeled at a variety of stages in the extraction and processing chain. There is demand for access to deposits, demand for concentrates at smelters, demand for refined metal by manufacturers or crude oil by refineries, and demand for minerals embodied in products such as cars or gasoline. The choice of processing stage often reflects availability of data, particularly since demand at other stages can be imputed (with varying degrees of success) from demand at the stage modeled. Many models have focused on demand for minerals in their most frequently traded form: finished but unwrought metal rather than ores or semifabricated products, crude oil rather than gasoline, and coal rather than electricity.

Time frame is of interest as well. The factors affecting demand, and the selection of modeling approaches, depend in part on the time horizon under consideration. Short run demand, or more correctly consumption, can be analyzed over a period of several months or a year. In other cases, the long term trends in demand may be of greater interest. A modeling approach that identifies broader trends would probably be ineffective in capturing shorter term demand fluctuations. Similarly, a method that represents the short run well is less likely to forecast major turning points successfully.

The three most common approaches to analyzing demand are estimation of demand functions, estimation of production functions, and the intensity of use technique. Demand functions have been widely utilized and reflect the first definition of demand presented here. They are typically econometrically derived relationships between quantity and the price of the mineral, the price of substitutes and perhaps complements, and some income variable such as GNP. As Radetski and Tilton (1990) point out,

> "This procedure can produce useful and interesting results; however, accounting in a realistic manner for the effects of technological change is often difficult. Properly specifying the relationship between

demand and its determinants, particularly the appropriate lag structure to use for the price variables, can also be troublesome. In addition the relationship itself may change over time in ways that make it difficult or impossible to estimate."

These core criticisms make econometrically derived demand functions more useful for short- than for long-range forecasting.

Production functions directly capture the relationship between inputs and outputs in manufacturing and reflect the view of minerals as factor inputs. Such process models tend to be very detailed and site specific (Sparrow 1980). While they can predict with excellent accuracy the amount of inputs required to produce a given level of output, they are not designed to address technological change over time. Leontief input-output models have also been used to analyze input demand; however, they too are based upon predetermined engineering methods and production functions (Miernyk 1965). These models are linear by definition; hence neither the effects of elasticity or changing technology can be captured. They are intended more to facilitate the analysis and interpretation of current or historic data than to be used as forecasting tools.

The intensity of use technique is of more recent origin, having evolved from the intensity of use hypothesis proposed by Malenbaum (1978). He argued that demand was a function of GNP and population. While this is no doubt true, the problem of capturing the effects of technological change over time remained. Tilton (1986) proposed that mineral demand was a function of the mineral content in final goods and the consumption of final goods. Change in demand over time would reflect "the overall level of national income, the material composition of products, and the product composition of income." This approach is intended for long range forecasting and has been developed in direct response to the failure of either the econometric demand functions or production functions to predict the downturn in metal demand that occurred in the 1980's (Roberts 1990).

Factors Affecting Mineral Demand

Numerous factors affect demand for energy and mineral resources. Rather than itemize all of the factors

impacting demand for each individual resource, examples of the types of factors are presented here.

Since all products of an economy are produced to satisfy consumer needs, it is to be expected that population growth will have positive influence on mineral demand. For example, phosphate rock is used to produce fertilizer which in turn increases the level of food production. The demand for phosphate rock will be affected by population growth.

Mineral demand is also affected by price changes and other economic activities. Mineral demand and price tend to be inversely related. Thus the demand for a mineral may decline as the price increases and vice versa. In some cases, there is a considerable elapse of time required for the mineral demand to adjust to its price changing. One reason for this time lag is the lack of immediate substitution potential, in part because substitution usually entails altering of production processes. If intermediate mineral consumers expect the price increases to be of short duration, it may not pay to change their current production processes. Only when intermediate consumers consider the price increases to be of a more permanent nature will they risk changing their production processes. A second reason is the resistance of manufacturers to try other processes with which they are unfamiliar. Consequently, it can take a few years before consumers respond to increases in the price of a particular mineral by curtailing demand.

Because minerals are raw materials that are used by many sectors of the economy to produce final products, changes in economic activity will affect the demand for minerals. Mineral materials are used as inputs in producing manufactured products. Therefore, changes in the technology of manufacturing of producer or consumer goods will have an impact on the demand for minerals.

In recent years, industries such as automobile and machinery manufacturing have expanded into global markets. As a consequence, parts for a car may be produced in two (or more) countries with assembly in a third country. Global competitiveness of this type has spurred manufacturers to improve the efficiency of production technology and to reduce the cost of production. Cost efficiency leads the manufacturer to seek the least expensive sources of mineral supplies and, at the same time, to demand high quality materials.

There are three components of the construction industry: residential, private nonresidential, and public works. Public works, such as highway construction, are a large consumer of stone and sand and gravel. The construction of the interstate highway system resulted in increasing the demand for stone and sand and gravel. However, due to completion of most of the interstate highway system, it is expected that the future demand for construction aggregates will diminish;

this downward trend will be moderated by the demand for these materials in maintenance of the highway system.

Mineral materials used in construction, such as crushed stone and sand and gravel are of low unit value and large volume, and they are not ordinarily shipped great distances. Therefore, the demand for these materials is localized in nature. The building of new housing will not only require some construction aggregates, but also will increase the demand for refrigerators, stoves, washers, dryers, plumbing, air conditioners, electrical systems, etc. These products are all made of numerous mineral materials such as copper, aluminum, and steel. In addition, if the home is in a newly developed area, new infrastructure, i.e., roads, sidewalks, sewer systems, and utility and power lines are needed to support the new development translating into more demand for crushed stone, sand and gravel, and metals.

The demand for minerals will be increased during wartime because the needed military hardware requires increased amounts of metals and some industrial minerals in addition to civilian requirements. Some military hardware to support a war effort is usually designed to operate under severe conditions requiring a number of durable, high performance materials.

Energy is demanded in the forms of electricity, heating fuels, and vehicle fuels. The level of demand is affected by the number of energy using vehicles and appliances, by the level of manufacturing activity, and by weather. For example increasing numbers of automobiles will lead to increased demand for gasoline; however, the increase is offset to some degree by gains in fuel efficiency. Prolonged hot weather leads to increased demand for electricity (to run air conditioners), while prolonged or severe cold raises the demand for heating fuels and natural gas.

Regulations affect the demand for minerals. For example, the fuel-efficiency standards for automobiles have caused, and will continue to cause, the manufacturers to change the automobile's design, reducing both its size and weight, resulting in heavier materials being replaced by lighter materials.

Recycling rates will also affect demand for virgin materials. As the Bureau of Mines (1991 p.1.10) points out "The term recycling as commonly used is not synonymous with continuous reuse, rather it is used for situations that only achieve life extension." They go on to note that "In most instances, recycled products are less effective than primary feedstock for the creation of new goods, and many current industrial processes can only accept a limited percentage of recycled feedstock." Total reliance on recycled materials is technically infeasible and economically unattainable. Nonetheless, recycling rates for most metals are increasing and technological advances are facilitating the use of secondary

materials.

Currently, recovery of lead from scrap batteries exceeds 60% of gross domestic lead consumption. Battery recycling is expected to reach 95%; however, many lead uses are dissipative so overall recycling rates are not expected to exceed 70%. Old copper and gold scrap[9] comprise 25% and 60% of domestic consumption respectively, while recycled aluminum (largely from beverage cans) provides 30% of aluminum domestically consumed. Recycling rates from these commodities, and others such as the Platinum Group Metals, respond to both market and regulatory forces; to the degree that recycling is profitable or required, it will be undertaken.

Substitution and Material Use Trends

Changing relative availability, technology or preferences can change the mix of materials used for shaping our physical environment. Materials may come from either renewable or nonrenewable sources. These materials include metals, minerals, and organic materials that are not consumed for food or energy uses. The traditional primary renewable resources are agricultural, forest, fishery and wildlife products. Primary nonrenewable resources are those which are created in geologic time, namely mineral ores, and organic materials derived from coal, petroleum and natural gas.

Since the beginning of this century, as shown in figure IIAiii-1 there has been a large increase in the use of nonrenewable organic feedstocks. These feedstocks are used to make plastics, petrochemicals, synthetic fibers, synthetic rubber, asphalt and other compounds. In addition there has been a marked increase in the use of nonrenewable materials from primary materials. Figure IIAiii-1 also presents the changes in total value of all materials consumed. Figure IIAiii-2 shows this shift in the proportion of nonrenewable materials from primary sources exclusive of secondary and recycled materials (by value in constant 1972 dollars) for nonfood and nonfuel uses in the U.S. between 1900 and 1989. At the beginning of this century renewable materials made up 73% of raw materials used. Minerals accounted for only 27% of our material needs. By 1989 materials from renewable sources had fallen to 37%. Nonrenewable resources made up the

[9]It is estimated that 85% of all the gold mined to date is still either in use or in storage in some form (Hodges 1995).

difference, rising to 63% of materials used in 1989. This trend could be described as suggesting the recent economy of the United States is consuming its capital rather than living on its income with respect to resources. Figures IIAiii-1 and IIAiii-2 identify the relative shares of material use. Overall all sectors have grown as shown in figure IIAiii-3. In 1989 we consumed in value terms almost three times as much material as at the start of the century. Much of this growth in material consumption by value can be attributed to a growth in population, and an increase in the prices of most raw materials by weight.

Traditionally, mineral commodities competition has been evaluated by comparing raw material cost on a weight basis. Historically, this has been an adequate methodology since the physical properties of mineral commodities have rather well defined boundaries which limited the areas of competition. However, with the introduction of polymeric materials and new metal alloys, the range of properties that can be obtained from a given primary feedstock has expanded, and the materials buyer can now more readily obtain the material attributes that are desired and avoid those that are not. The ability of the material engineer to deliver the desired properties without the traditional constraints imposed on mineral commodities is critical to intermaterial competition. Often we obtain the properties that we desire more efficiently by using materials which give us these properties at lower cost. Material selection can now encompass such considerations as lower costs achieved for varying production runs, the ability to make complex parts in a single operation, improved performance in use, simpler installation, and resistance to breakage, corrosion, etc.

On a weight per capita basis, figure IIAiii-4 shows the consumption of various materials from 1966 to 1989. The materials included are steel, aluminum, copper, plastics, wood and wood pulp. figure IIAiii-5 shows the volume, in cubic meters, used per capita for the same materials. These figures show a decline in the use of steel per capita by weight and volume. Plastics usage increases over the period while copper and aluminum remain relatively constant as do wood and wood pulp. The decrease in steel can be partially ascribed to downsizing, and the increase in the use of lighter weight materials such as plastics in transportation applications, and a decline in the maintenance of infrastructure applications such as roadways and bridges. Plastic has also penetrated many of the renewable markets such as fibers, packaging, and consumer goods. In the case of paper, penetration of the packaging market by plastic has been offset by increased applications in areas such as xeroxing and printing.

The use of primary materials is also reduced by the increased recycling of material. Currently, more than a third

of metals used come from secondary (recycled) sources. To date only a small proportion of plastics are recycled but the trend is upward. Plastics News reports that 31.1% of plastic soft drink bottles and 6.6% of milk jugs were recycled in 1990 compared to 23.4% and 1.4%, respectively, in 1989. Overall recycling of plastics in packaging has risen to 3.7%.

Consumers and manufacturers have also altered their choice of energy inputs over the past 20 years. Energy sources are best compared in terms of Btu usage as comparison of cubic feet of natural gas to short tons of coal would not be particularly meaningful. As noted earlier in this report a Btu, or British Thermal Unit, represents the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit. The heat content of one barrel of domestically produced crude oil is approximately 5.8 million Btu's (USDOE, EIA 1992). The average heat content of a cubic foot of dry, domestically produced natural gas is 1,031 Btu's. A short ton of domestic coal contains about 21.7 million Btu's.

As figure IIAiii-6 illustrates, use of energy from coal has steadily increased in BTU terms over the past 20 years. Petroleum usage has dropped from its peak in the late 1970's, but has recovered from low point in the early 1980's. Usage of natural gas as a source of Btu's also dropped in the early 1980's, but has since recovered. Usage of energy from hydroelectric sources has remained steady, although nuclear has gained some market share. These changes in relative market share reflect consumers' evaluation of a number of factors, including relative price per Btu, security of supply, environmental costs associated with each energy source, convenience and appropriateness to specific engineering designs or requirements.

Price, policy, or technology driven substitution among resource inputs has long term implications for resource demand. A shift away from copper to fiber optic cables could dampen overall demand for copper. Refitting automobiles to burn natural gas would negatively impact crude oil demand, as would increased use of electric cars. At the same time these changes could lead to increased demand for natural gas and coal (for electric power generation.) How these issues could affect demand for specific energy and mineral resources is addressed in the Commodity section of this report.

RESOURCE OWNERSHIP AND RELEVANT LEGISLATION

In many countries, all energy and mineral resources belong to the state. This is not the case in the United States where ownership of nonrenewable resources may be public or private. For privately held energy and mineral resources, access is granted by the owner and development occurs in response to market forces. Government involvement is mainly in the form of taxation and environmental regulation.

The situation for publicly held resources is somewhat different. Access to energy and mineral resources on public lands is regulated by one of several laws, depending upon ownership status and type of resource. Although exploration, development, and extraction are still undertaken by private parties in response to a profit incentive; however, access to resources is often controlled and regulated by the government. In this section categories of public land ownership are identified, applicable energy and minerals laws briefly reviewed, and the relationship between land status and surface occupancy rights addressed.

Land Ownership

The continental United States comprises lands gained by conquest (from the English Crown and from Mexico), by purchase (from France, Spain, Russia, and Mexico), and by treaty (with England.) Over time, much of this land was transferred to private ownership through the patent process. The balance has remained in the Federal estate and is now termed Public Domain. The Public Domain is occasionally enlarged through land exchange. The General Exchange Act (1922) directed that a newly acquired parcel be designated as Public Domain if the land for which it was being exchanged was Public Domain. (The parcel would otherwise be Acquired land, a topic addressed below.) The original Forest Reserves set aside by Presidents Harrison and Cleveland, and added to by Roosevelt, were all withdrawn from Public Domain lands.

The Weeks Act (1911) authorized withdrawal of remnants of Public Domain lands in Florida, Arkansas and the Lake States for National Forests. The Act (and its amendments) also provided for land acquisition by the Secretary of Agriculture through outright purchase or by exchange. The Bankhead-Jones Act (1937) also authorized Federal

acquisitions through the repurchase of homesteaded lands. Some of these were later transferred to the Forest Service for administration, mostly as the National Grasslands. Private lands that are reacquired by the Federal government via the provisions of either of these Acts are termed Acquired lands.

The National Forest System is a mosaic of Acquired, Public Domain or reserved from Public Domain lands. In most instances, the surface and subsurface belong to the same public ownership category, but this is not always the case. For example, some Bankhead-Jones lands have Public Domain subsurface underlaying Acquired surface. This occurred because the homestead patent transferred ownership of surface only, so the subsurface never left the Federal Estate.

It is not uncommon for a Federally controlled surface to be underlain with privately held minerals, either reserved or as part of an unpatented mining claim (discussed below). There could have been other reasons why the mineral rights were not purchased when the surface rights were acquired. The mineral rights may not have been for sale, may have been deemed too expensive, or the probability of development may have been considered too small to warrant the expenditure.

When a private land owner transfers the surface only to the Federal Estate through a purchase or exchange agreement, the parcel is classified as either Public Domain or Acquired land, depending upon the legal authority cited (e.g., Weeks or General Exchange Act) for the acquisition. If any portion of the subsurface is retained by the landholder (e.g., oil, coal, gold or the entire estate), the mineral rights are termed Reserved.

Reserved minerals are private property and their presence is termed a Valid Existing Right (VER). The terms of each energy or mineral reservation are negotiated with the Federal Government by the private landholder on a case by case basis. The mineral deed is usually specific as to what can be done with the mineral estate. Typically, the reservation is for a stated period of time, say 50 years, after which the resource is conveyed to the Federal Government. Thereafter the minerals are classified as Acquired. There may be provisions in the original conveyance that allow for continuance of the reservation beyond the termination date if there is ongoing production.

Mineral ownerships, including reservations, usually carry some right to use of the surface for activities related to extraction and processing operations. The degree of control the government has over development and extraction of reserved minerals is conditioned by whichever set of the Secretary of Agriculture's Rules and Regulations (1911, 1937, 1947, 1963) were in force at the time of acquisition. These Rules afford varying degrees of surface control authority to the

Forest Service.

Ownership of the mineral estate may have been severed from surface ownership prior to transfer of the latter to the government. The present owner of the subsurface would be under no obligation to sell to the government, and if no such parallel sale were made, the subsurface would remain private. Again the surface might be Public Domain or Acquired land; the privately owned subsurface mineral rights would now be termed Outstanding.

The Secretary's Rules do not apply to outstanding mineral rights. In these instances, the exercise of the rights is conditioned by the specific language conveying the mineral rights to the private party. Surface control authority can range from none to quite comprehensive depending upon the wording of the conveyance, existing State laws, and Court interpretations. Again, this type of private ownership is a VER, i.e., a private property right.

There are, unfortunately, almost infinite combinations of land ownership and mineral rights. A parcel of land could be subject to a mix of Federal and private (including Reserved, Outstanding, fractional, and/or future) rights, each applying to a different resource or a different part of the same deposit. It is not uncommon for different subsurface resources to have different owners. There are even instances where different coal seams have different owners. Sections of a Forest acquired at different times may be subject to different sets of the Secretary's Rules. All of this makes administration of mineral rights enormously complex.

Approximately 10,232,000 acres of the lands administered by the Forest Service are subject to minerals reserved or outstanding in the third parties (table IIBi-1). When administering operations involving private minerals, the Forest Service reacts to a decision by the private mineral owner to develop their minerals. The Forest Service obtains surface protection under: 1) the terms of the deed of mineral severance or the terms of the deed to the United States: 2) applicable state and Federal laws; and 3) cooperation with the operator. In general, it is not the policy of the Forest Service to actively pursue the purchase of minerals not acquired at the time the surface was acquired. However, in some cases that involve mineral development in wilderness areas, the agency has purchased the minerals rather than allow their development.

Major Energy and Mineral Laws

Energy and mineral resources on public lands are administered under a set of laws separate from those which established the Forest Service or now guide overall public land management policy. Land ownership status and type of mineral dictate which resource law takes primacy in any given circumstance. The majority of mineral laws have a common intent, to encourage and facilitate the discovery and development of mineral resources. To the degree that conflict between surface and subsurface use results, mineral laws frequently take precedence. It should also be noted that management of subsurface resources is largely the responsibility of the Department of Interior, Bureau of Land Management (BLM), regardless of which agency is responsible for the surface estate.

Although there are numerous laws and amendments applicable to minerals management, those listed here are of particular importance: the Mining Law (1872), the Mineral Leasing Act (1920), and the Mineral Materials Act (1947), the Mineral Leasing Act For Acquired Lands (1947), and the Federal Onshore Oil and Gas Leasing Reform Act (1987). Only the basic provisions of these Acts will be described here.

The Mining Law of 1872 (as amended) is applicable only to minerals in the Public Domain (or on lands reserved from Public Domain). All minerals other than those specifically excepted by subsequent legislation are covered. Although a complete listing of affected minerals is too extensive for inclusion here, a few examples may be illustrative: copper, lead, gold, zinc, uranium, gems, chemical grade limestone, and asbestos.

Minerals managed under the Mining Law are referred to as locatable minerals because the law provides for self-determination, free access, claim staking, and the right of patent. Patenting a claim transfers fee simple ownership of the surface and subsurface to the individual or firm holding rights to the claim. The phrase self-determination means that decisions regarding exploration targets and timing are made by those doing the work, rather than the government. Free access means that any U.S. citizen or corporation may enter any public lands, not specifically withdrawn, to explore for any mineral covered under the law.

If evidence of a deposit is found, a claim can be staked, which affords the holder exclusive rights to any locatable minerals subsequently found, as well as use of the surface for activities incident to mining. Privately owned unpatented mining and millsite claims are valid property rights in the fullest sense and may be transferred, bequeathed, or taxed, subject only to the right of the United States to reasonably regulate surface disturbances. The law provides for lode and

placer claims, as well as mill and tunnel sites. A claim is not strictly necessary to mine on the public lands open to mineral entry, but because it protects a miner's discovery from other prospectors and serves as the basis for patent, claims are usually filed.

Claims are recorded with the BLM and the county. The claim effectively grants unlimited tenure so long as a $100 fee is paid each year. The claim can be patented upon demonstration of the presence of a valuable mineral deposit[10], completion of $500 of development work and compliance with various other regulations.

As of the end of fiscal year 1992, there were 1,010,003 unpatented claims of record on public lands (table IIBii-1) (USDI BLM 1994). By September of 1993 this number had decreased to approximately 300,000 due to the imposition of a $100 annual fee and the requirement that the first 2 years be paid at once. In addition, a total of 4,928 claims had been patented as of the end of 1992, of which 257 went to patent during that year[11].

Prior to patent, the Forest Service regulates the surface impacts of locatable mineral operation through a Plan of Operations under 36 CFR 228, Subpart A. The purpose of these regulations is to minimize adverse environmental impacts from mining activities on National Forest resources. The operator is required to submit a Notice of Intent for mineral activities on the NFS and must submit a Plan of Operation for activities that are likely to cause significant disturbance to surface resources. The agency reviews, and if necessary recommends modifications to, operating plans so as to minimize environmental impacts of mining activities, including setting requirements with respect to air and water quality, solid waste disposal, scenic and cultural values, fisheries and wildlife habitat, road maintenance and reclamation. The operator is required to post a bond covering the estimated cost of reclamation.

The decision of whether to allow a locatable mineral operation is not discretionary on the part of the Federal government. Federal agencies cannot deny the right to conduct mining operations on Public Domain lands except in cases where the proposed mine would be in an area previously withdrawn from mineral entry, or in those few cases were an environmental clean-up under federal hazardous material law is occurring under Forest Service direction. Agencies do

[10] A valuable mineral deposit is one for which there is a reasonable expectation that the resource can be extracted at a profit given current markets and technology. Demonstrating economic viability can be both expensive and time consuming.

[11] The BLM does not currently identify surface managing agency for each claim. FS Minerals and Geology Management staff estimate that as many as 60% of the claims may lie within the administrative boundaries of NFS lands.

have considerable discretion with regard to setting requirements for the plan of operation, including limiting surface occupancy and restricting work to certain times of year. Nonetheless, mutual agreement with the operator is typically required as both parties must sign the Plan of Operations.

Upon patent, agency control of the surface effectively ends as fee title is now completely privately held. However, since some mineral operations take place on a mix of private and public lands, overlain with unpatented claims, some level of Federal oversight of operations on remaining federal lands may continue even after patenting. There are no requirements for reporting production and there is no federal royalty on locatable minerals, either before or after patent.

The Mineral Leasing Act of 1920 originally applied to sodium, phosphate, gilsonite, and potassium on Public Domain lands. Subsequent Amendments and legislation (e.g., Mineral Leasing Act for Acquired Lands (1947) and the Geothermal Steam Act (1970)) extended the reach of this law. Currently, in addition to the previously mentioned resources, coal, oil, gas, oil shale, sulfur deposits in Louisiana and New Mexico, and geothermal resources on Public Domain lands are deemed leasable minerals. On Acquired lands, all energy and mineral resources, except common varieties, are leasable.

A lease is an agreement between the mineral owner (i.e., the United States) and the lessee, which when issued becomes a binding agreement that grants the lessee certain rights subject to terms, stipulations, and provisions. In exchange for the rights, the lessee makes payments, in the form of bonus bids, rentals, and in the event of production, royalties. Royalties are collected by the Department of Interior, Minerals Management Service (MMS). Leases are issued and records maintained by the BLM and production statistics are reported to that agency.

The law regulates exploration, leasing and royalty taxation, although specific requirements and authorizations differ by resource. In general, U.S. corporations or private citizens may enter any public lands not specifically withdrawn from mineral activity to explore for any resource covered under the law. Prospecting permits for locatable minerals are not required on lands open to mineral entry. However, to the extent that prospecting activities will cause significant surface resource disturbance, this must be addressed in an approved Plan of Operations. Prospecting permits for mineral materials are required on acquired lands.

Leases for solid mineral resources on acquired lands are awarded via preference right, i.e., the prospecting permit holder will be issued the lease if he/she discovers a "valuable" mineral deposit. Under the Mineral Leasing Act (1920)

persons demonstrating the discovery of commercial coal deposits under prospecting permits issued by the Secretary of the Interior would be awarded a preference right lease to mine the coal. The Federal Coal Leasing Act (1976) repealed the preference right leasing system, fostered diligent development of leased reserves, and required preparation of a comprehensive land use plan before lands are offered for lease (USDOE, EIA 1992). Coal leases are now usually awarded through sealed bid competition. Successful firms must post bonds and operating plans must be approved by the land management agency.

In the case of oil and gas, lease lotteries were held prior to 1987. Since passage of the Federal Onshore Oil and Gas Leasing Reform Act (1987), lease auctions have utilized a competitive sealed bid process[12]. The highest bidder acquires the lease, which provides the holder with exclusive right to explore for and produce to exhaustion any leasable minerals discovered on that tract. Competitively awarded leases run for 5 years, during which period the firm must begin production or the lease terminates. Once production commences, the lease runs indefinitely or to the exhaustion of the deposit. Parcels that do not sell at auction are available for lease on a noncompetitive basis for 2 years after the sale. Noncompetitive leases run for 10 years if there is no production, and indefinitely once production has commenced.

The Leasing Reform Act had several other provisions that affected the Forest Service. Federal land management agencies no longer react to proposals from a lease applicant, but rather are viewed as the proponents because lands must be put up for competitive sale by the BLM. The Forest Service was given authority to regulate and approve all surface disturbing activities for leases on NFS lands and to determine reclamation standards. The agency also may determine the amount of bond necessary to ensure reclamation of surface disturbing activities and ascertain whether or not an entity has failed or refused to comply in any material respect with the reclamation or other standards of Section (g) of the Act. The Secretary of the Interior cannot issue a lease or approve the assignment of a lease to such an entity until they come into compliance.

Table IIBii-2 lists oil and gas leases on Federal lands as of the end of fiscal year 1992 (USDI BLM 1994). Table IIBii-3 lists energy and mineral leases on NFS lands.

For any lease, the Forest Service maintains responsibility for the surface estate, as title to the land does not

[12]There was a moratorium on oil and leases for several years while Environmental Impact Statements were being completed. The moratorium has since been lifted.

transfer to the leaseholder. The agency reviews, and if necessary recommends modifications to, operating plans so as to minimize environmental impacts. Once a lease has been granted, the FS cannot deny the lessor the right to extract without sufficient cause.

The purpose of the Mineral Materials Act (1947) was to place certain mineral and non-mineral resources outside the scope of the other mineral laws because of their "common" nature. Common varieties of sand, stone, grave, pumice, cinders, clay, as well as vegetative materials such as yucca, mesquite, and cactus are included. These materials are subject to a permit/sale system for their exploration and development. The United States retains ownership of the surface and subsurface and regulates Surface use Plans of Operation so as to minimize environmental impacts.

Saleable minerals are administered under Forest Service regulations at 36 CFR 228, Subpart C. Their disposal is discretionary on the part of the agency. They are sold, or in some cases disposed of through free use, under the terms of a Mineral Material Permit issued to the permittee by the agency. Once issued, the Permit is a legally binding contract between the FS and the permittee. The permit contains specific terms and conditions, plus any additional terms and conditions deemed necessary in each specific case to minimize adverse environmental impacts. As with leasable minerals, salable minerals may be sold either competitively or non-competitively (negotiated sale). However, in either case the sale price must be at or above the appraised value of the resource.

ENERGY AND MINERALS IN THE UNITED STATES ECONOMY

During the period of 1977-1992, the U.S. Gross Domestic Product (GDP[13]) increased from $1,958 billion to $5,950 billion (Economic Report of the President 1992). To support this high level of GDP, the U.S. economy in 1992 required $32 billion (market value) of domestically produced nonfuel-minerals plus over $100 billion (market value) of domestically produced crude oil, natural gas, and coal. In addition to domestic production of raw materials (primary supply), the U.S. economy also depended upon domestic reclaimed metals and mineral materials (secondary supply), and imports of energy and mineral raw materials (foreign supply). The availability of mineral resources and their subsequent production are vital to support vigorous economic growth. Without domestic nonrenewable resource production or foreign imports, the production of most industries that contributed to GDP could not be sustained.

The significance of energy and mineral resources to the United States economy can be viewed in two related ways. The first perspective focuses on the nonrenewable resource sectors as producers of inputs essential to manufacturing, agriculture, and construction. Nonrenewable resource availability is linked to economic growth and wealth creation, leading to a view of these resources as a form of capital asset capable of earning a financial return. The second perspective considers the extractive industries as generators of employment and income, as well as contributors to Gross Domestic Product (GDP) and Gross State Products (GSPs). Both approaches will be covered here.

Minerals as Endowed Wealth

[13]With a GDP accounting stance, only those economic activities taking place within the United States are reported. GNP accounts for both foreign and domestic economic activities undertaken by U.S. firms and households. Given the magnitude of domestic resource firms' international activities, it is not surprising to find that the industries have contributed more to GNP than to GDP. For example, nonrenewable resources accounted for 4.99% of GNP in 1977 (on a 1982 constant dollar basis) but only 2.56% of GDP for the same year. DOC now reports only GDP.

Economies grow and create wealth through the production and accumulation of human and physical capital. Human capital refers to the intellectual assets, the skills and knowledge of the work force. Physical capital is defined as the tangible assets used in the production process. More generally, capital can be thought of as all those assets capable of generating physical or psychic income for individuals in the future. A country's wealth at any given point in time is the value of this capital stock.

Much economic growth analysis has stressed the human and technological assets, but the role of raw materials should be acknowledged as well. Historic periods of humans, the stone, copper, bronze, iron, coal, and nuclear ages have been named for the principal mineral resource of the era. In each case, improvements in production methodology and societal well being can be related to the availability of a successively better raw material or fuel. (Myers and Barnett 1985).

On a worldwide scale, the rate of economic growth is related to the quantity of energy and mineral resources available. However, the existence of natural resources in any single country has no deterministic power over the scale and location of development (Rees 1985). There are numerous examples of resource-rich poor countries, such as Mongolia, and resource-poor rich countries, such as Japan.

Moreover, for energy and mineral resources to generate growth, they must be located, extracted and function as factors of production so as to be converted into useable products. In additional to natural resources, manufacturing processes also require two other basic inputs: labor and physical capital. Within the limits of technology, firms select some combination of these inputs so as to maximize profits. A change in the cost or availability of any one can lead to a shift in the ratios among them all.

Natural and physical capital have certain characteristics in common. Both are produced as inputs to current and future production; that is, they yield productive services over time. Expenditures are required to "produce" additions to the stock of energy and mineral reserves, just as is the case with other forms of capital. However, nonrenewable resources do differ from physical capital in one significant respect. As pointed out by Landefeld and Hines (1985), "they are not fully produced by the economic system."

While the value in the market place of both resource-based and physical capital reflects the cost of economic inputs used in their production, the return available from alternative investments, and relative risk, mineral values include

an additional component. Their value in the market place reflects a return to the resource itself. Assuming a competitive market, any surplus of market price over extraction cost represents some combination of differential (or Ricardian) rent and scarcity (or Hotelling) rent. The former arises from the nature and location of the resource deposit. The latter represents the economic depreciation, or decline in the selling price, of the deposit due to extraction. The difference between market price and production cost can vary from near zero (for marginal deposits where extraction cost approaches price) to a large percent of price (for inframarginal deposits of high quality).

As noted previously, wealth can be defined as accumulated capital. Energy and mineral resources are part of societal wealth because they can be thought of as a form of capital stock. However, part of the income generated by nonrenewable resources stems from their intrinsic nature as nonrenewable resources, i.e., Hotelling rent, leading to their classification as endowed rather than accumulated wealth.

No attempt has been made here to calculate a comprehensive set of rents for all resource deposits. That would require detailed knowledge of marginal costs by deposit and is beyond the scope of this report. Data are available, however, on industry costs, revenues, and value added, from which a general approximation of the excess of pretax revenues over expense can be derived. These data also illustrate how the potential for profit in the extractive industries has changed over time and so will be considered here in some detail.

The Department of Commerce (DOC) reports the "value of shipments and receipts," which represents revenues from shipments of all products, plus receipts for work done for others, for all mineral establishments[14] (USDOC Bureau of the Census - various years). Also reported are capital expenditures, labor costs, and costs for supplies, fuel, electricity and other inputs. Table IICi-1 (Col's 1,2,3,4) shows these categories for the metallic ores sector (SIC 10) for 1958 through 1987[15] in 1982 $'s. Tables IICi-2 through 4 show these same data for coal (SIC 11,12), oil and gas (SIC 13), and nonmetallic minerals (SIC 14) respectively.

Column 5 of Tables IICi-1 through 4 reports "value added" (VA), which is calculated by the Bureau of the Census as value of shipments and receipts plus capital expenditures less cost of production, (i.e., Col 5 = Col's 1 + 2 - 4).

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[14]Mineral establishments includes both mineral producers and mining and petroleum services companies.

[15] The DOC Census of the Minerals Industries is conducted every 5 years. The most recent Census, that of 1992, has not yet been published.

The DOC Bureau of the Census views their form of VA as "the best value measure for comparing the relative economic importance of [an energy or minerals related sector]" (USDOC 1989 p. A-2). It measures both value added by resource production and property development.

The DOC, Bureau of the Census, VA figures are not comparable to, and cannot be reconciled with the DOC Bureau of Economic Analysis (BEA) estimates of VA, termed Gross Product Originating (GPO). The Bureau of the Census estimates are based on an establishment level survey, while some GPO data are available only on a consolidated company basis. Moreover, GPO is based on national income and product account definitions and as such includes sales and excise taxes, and excludes purchased services. (The DOC, BEA GPO figures are discussed in detail in the following section of this chapter.)

For the years surveyed, the constant dollar VA for metal mining reached its maximum in 1972, then dropped in 1977 and again in 1982 (figure IICi-1). However, by 1987 the VA estimate had returned to 1967 levels. The real VA for nonmetallic mining has also increased, dropped, and then increased again. Both metallic and nonmetallic mining are sensitive to general economic conditions, so it is not unexpected that value added would be low in 1982, a year during which the economy was in recession.

The real VA for coal rose dramatically between 1972 and 1977, reached its apex in 1982, and had declined by 1987. This reflects an overall increase in the value of energy resources following the oil embargo and the subsequent drop in energy prices in the late 1980's. Not surprisingly, constant dollar oil and gas VA follows a similar time path (figures IICi-2 and 3).

The data upon which VA are based can also be used to estimate the pretax net revenue. Column 6 in Tables IICi-1 through 4 reports the "value of shipments and receipts" net of all reported expenditures for labor and other factor inputs, including additions to physical capital (Col 6 = Col's 1 - 2 - 3 - 4). Prior to interpreting these data, several important caveat are in order.

First, the initial value of sales is the sum of revenues from the sale of mineral products, plus sales of other secondary products and revenues of mining services companies. For the metal, coal and nonmetallic mining segments, these additional revenues represent approximately 3.0%, 1.5%, and slightly over 0.0% of total revenue. Thus the net revenues calculated from the DOC data can be interpreted as basically representative of these primary commodity

industries. In contrast, revenues from drilling, exploration, and field services represent almost 10% of the value of shipments and receipts for the oil and gas extraction industry. It is possible to remove these non-resource revenues, but associated factor costs cannot be broken out and removed as well. Thus, the net revenue estimate is not strictly representative of the oil and gas commodity sector.

The second area for concern is that of capital expenditures. Some expenditures for capital equipment, particularly installed machinery, may be included in both the "capital expenditure" and "cost" categories. If so, they will have been subtracted twice, leading to an under estimation of net revenues. The data reported by the Bureau of the Census are not provided in sufficient detail to determine the magnitude of this potential discrepancy.

Finally, it should be emphasized that these values are all pretax. No attempt has been made to calculate after tax profit[16] and these numbers should not be interpreted as either return-on-investment or profitability. Furthermore, the costs removed from value of shipments reflect neither the cost of financing nor the effect of currency fluctuations. These are both important factors, given the large capital investments required for mineral development, and the international nature of the industry. It may well be that once taxes, royalties and financing charges are removed, little or no revenue would remain in some years. In addition, it should be emphasized that the return to any individual establishment, or any deposit, may be high, low, or even negative.

In figures IICi-4 through 7, value of shipments, total costs[17], and net revenue are graphed for the metallic ores, coal, oil and gas, and nonmetallic minerals sectors respectively. In each sector, net revenue remained fairly constant until at least 1972. Thereafter the picture changes. During the period following 1972, the metals industry enjoyed an increased value of shipments. Unfortunately, costs rose as well, eventually surpassing revenues. The result was negative net returns for a number of years. As the industry brought costs down through rationalizations, technological advancements and productivity increases, net revenues became positive.

Variations on this relationship between the rate-of-change of costs and rate-of-change of revenues are repeated in every other segment of the industry. The nonmetallic minerals sector of the industry saw net revenue increase sharply because the value of shipments increased faster than costs after 1982. Similarly in the coal sector, net revenue increased

[16] Data necessary for tax calculations were not available.

[17] Total Cost = Col's 2 + 3 + 4

even as the value of shipments decreased, because costs were dropping faster than revenues. The oil and gas sector shows yet a different outcome. Both costs and revenues have fallen since the strong oil market period in the late 1970's - early 1980's. Because the value shipments has fallen more rapidly than costs, net pretax revenue has fallen as well.

An alternative view of these data is shown in figure IICi-8, which illustrates the ratio of net pretax return to real value of shipments for the energy and mineral sectors. This relationship has been quite variable in all 4 sectors. Even nonmetallic minerals, the least variable sector, had net revenue/value of shipment ratios that ranged from 18.6 in 1982 to 32 in 1987, a 72% difference. The other sectors evidenced even broader ranges, with metals the most volatile. One possible cause of the marked changes from year to year may be the volatility of resources prices. The extractive firms production and capital costs are relatively consistent year to year, if new mine development is excluded, but revenues reflect changing market prices.

As a final step in this brief discussion of minerals as endowed wealth, the DOC data will be used to estimate the revenue potentially available as a return to resource-based capital assets. The product of the Treasury Bill rate and value of gross capital[18] has been designated as an approximation of minimum return to physical capital i.e., what the physical capital could earn in its next best alternative investment. This has been subtracted from pretax net revenues to yield pretax revenues net of all expenses including a minimum return to capital (table IICi-5). This final value has been positive for most sectors (except for metals) in all years and has been increasing in recent years, suggesting that a return, over and above the returns to physical capital, may have been earned by energy and mineral resources themselves. These returns may or may not ultimately have accrued to private resource owners or developers depending upon tax and financing considerations.

Energy and Minerals in the Gross Domestic and Gross State Product

As Randall (1981) has pointed out, "the resource owner converts wealth - i.e., minerals in the ground - to current

[18]Gross capital by industry segment is reported by DOC; no estimate of depreciated capital is provided by DOC. The corresponding year's average 3-month Treasury Bill rate has been selected as a proxy for risk-free return.

income by extracting and selling the resource." The income generated from this activity and reported as part of GDP does not equal the market value of resources produced. This is because GDP represents the value of final goods and services produced in the economy. Including the full market value of each factor input at each stage of production would result in double or triple counting or more. Instead, each industry's contribution to the GDP represents the value added by their activities to the goods and services that make up final production or demand. This amount is termed the Gross Product Originating (GPO) in the sector by the DOC, Bureau of Economic Analysis (BEA) and differs slightly from the definition of value added used by the DOC, Bureau of the Census, and discussed in the preceding section.

The contribution of the energy and minerals industries to GDP on a constant dollar basis, for 1977 through 1990, is shown in Table IICii-1 (USDOC BEA 1995). In 1977, these industries together accounted for almost 2.56% of overall GDP. By 1990, their share had declined to 1.78% on a constant dollar basis. This change occurred because over the 13 year period GDP doubled, while the resource sector contribution to GDP increased by only 56%. Contribution to GDP by the coal, oil and gas, and nonmetallic minerals sectors decreased between 1977 and 1990. Some of this decrease reflects decreases in real resource prices over the period. For example, the real price of a short ton of coal was $30.20 in 1977 (1982 constant $s), but had declined to $16.32 by 1990[19]. In other case the declining contribution to GDP stems from a decrease in domestic production. For example, 1977 production of crude oil was 8.24 million barrels per day, whereas only 7.36 million barrels per day were produced in 1990[20].

Only the metallic ores sector increased its percentage of GDP over the 1977 to 1990 period. This reflects a major increase in domestic gold production, as well as the advent of platinum group metals production in Montana. Output of most other metals has not changed significantly over the period. The level of domestic energy and minerals production reflects the overall state of the economy, government policies and regulations, and the availability of alternative sources of material. Exploration expenditures and activities tend to be focussed on areas of geologic interest. But within that constraint, energy and mineral firms will shift production activities to those regions of the United States and the world

[19]Energy and minerals prices are discussed in more detail in the commodity section of this report.

[20]Commodity production in discussed in more detail in the individual commodity chapters of this report.

where development can proceed expeditiously and where they expect to be most profitable. In recent years many energy and minerals firms has shifted part of their exploration and production activities outside the United States, an issue addressed in more detail in section IIE. Energy and Mineral Industry Technology and the Environment.

Although the overall percentage contributions to GDP are small for all four sectors, this is not indicative of the full importance of the energy and minerals industries to the United States economy. The prior section stressed the basic nature of these industries and the need for energy and mineral resources as factors of production. In addition, the importance of these sectors at the regional, and particularly state and local levels, can be much greater[21]. Contribution of the energy and minerals sectors to GSP's is reported in tables IICii-2 and IICii-3, for 1977 and 1990, at the 2 digit SIC Code level (USDOC, BEA 1995). Data are reported in 1982 constant dollars (deflated using BEA's sector-specific price deflators) and nominal dollars for each state, organized by RPA region. Market value of sales is not shown. These data take a GDP accounting stance, i.e., when all the GSP's are summed, they equal GDP rather than GNP.

As noted previously, the contribution of the energy and minerals sectors to GDP has decreased from 2.56% in 1977 to under 2% in 1990, on a real dollar basis. State level contribution was much higher in a number of cases. In 1990, the nonrenewable resource sectors accounted for the following percentages of GSP (on real terms): 35% for Alaska, 31% for WY, 15% for Louisiana, 15% for West Virginia, and 11% for New Mexico. The extractive sectors have also figured prominently in the economies of several other states, including Oklahoma, Montana, Nevada, North Dakota, and Texas. In states such as California, the industry is large, but its contribution to GSP is swamped by the overall magnitude of the state economy. In states such as Arizona, the industry does not account for a major portion of the overall economy, but is the driving factor in selected counties.

Several interesting trends can be observed when examining in these data. Overall, metal mining's importance to GDP decreased slightly between 1977 and 1990. Similar trends can be observed in individual states. For example, in 1977 the metal mining sector contributed 2.24% of Arizona's GSP (real $s). This was the largest state level impact the sector made in that year. Wyoming ranked second in terms of the importance of metal mining at 1.86% (real). By 1990, metal mining's contribution to GSP had shrunk in both states, though for different reasons. In Arizona, value added attributed to metals increased in real terms from $423MM to $805MM between 1977 and 1990, a rise of 90%, but total GSP

[21]Energy and minerals contribution to rural economies is addressed at length in Section V.A. of this report.

increased more than two and a half fold. Consequently, mining's share of GSP decreased. During the same period, value added from metal production decreased in Wyoming even as GSP almost doubled. It should also be noted that the majority of the growth in the Arizona economy came in non-resource sectors, whereas much of the growth in Wyoming is attributable to the energy and nonmetallic mining sectors.

This trend of decreasing importance of metal mining has been dramatically reversed in Nevada. In 1977, metal mining accounted for a mere .66% (real) of the state economy. By 1990, the sector contributed fully 7.23% (real) of GSP. Value added (in 1982 $s) increase from $47MM to $1752MM (more than 35 fold), while GSP increased from $7142MM to $21,218MM (slightly less than 3 fold). Clearly mining has become an important sector in the Nevada economy, particularly in rural areas geographically removed from the major resort cities.

Coal mining contributed .49% of GDP in real terms in 1977 but by 1990 the figure had slipped to .31% (real). Unlike the situation with metals, the coal industry has not become newly prominent in any state's economy. Rather, the sector has consistently been a significant factor in the economies of West Virginia, Wyoming, Kentucky, and Montana, and to a lesser degree important for New Mexico, Alabama, Virginia, and Pennsylvania. In real terms coal mining accounted for almost 13% of the West Virginia GSP and over 10% of Wyoming's GSP in 1990. The industry represented 4.74% of the Kentucky economy in 1990 and was the driving economic force for many rural eastern counties. This is often the case for the extractive industries; even in states where they are important, their impact may be limited to those counties where coal or mineral deposits or oil fields are located.

Of all the nonrenewable resource sectors, oil and gas contributed the most to GDP and to individual GSPs between 1977 and 1990, this despite the downward trend noted earlier. The changes in value added for this sector illustrate both the industry's expansion during the late 1970's and early 1980's and the shrinkage of domestic activity since the collapse of oil prices. In 1977, oil and gas accounted for 19% of Louisiana's GSP. By 1990, that figure was 14.76% (in real terms). The trends are similar for New Mexico, Oklahoma, and Texas. In each case, the percent of GSP attributable to the oil and gas sector had shrunk even as constant dollar value added increased. This reflects two relationships: the overall direction of the state economy relative to that of the industry, and the ratio of commodity sale price to the cost of inputs relative to that relationship for other sectors.

While the nonmetallic mining sector has been accounted for between 3% and 4% of the Wyoming economy since

1977, the sector contribution to GSP is less than 1% in every other state. This is so despite the fact that the sector's constant dollar value added is larger in several other states, e.g. California, Florida, and Georgia, than it is in Wyoming. Once again it is clear that the importance of any single sector is dependent upon the overall size and makeup of that state's economy.

Energy and minerals contribution to regional economies differs dramatically across the RPA regions[22]. On a constant dollar basis, nonrenewable resources accounted for only .57% of overall GSP in the Northern region, but 4.48% in the Rocky Mountain region and 3.6% in the Southern region in 1990. The oil and gas sector was prominent in the south, whereas metals and oil and gas were important in the Rocky Mountain region.

Wages and Employment in the Energy and Minerals Industries

Overall employment levels in the energy and minerals industries for 1977 through 1993 are reported in Table IICiii-1 (USDOL, Bureau of Labor Statistics - various years). Employment in all sectors of the industry peaked in the late 1970's or early 1980's, with oil and gas experiencing the greatest expansion. Thereafter, job numbers declined to below 1977 levels for all sectors (figure IICiii-1). This latter change reflects both declines in production levels (oil and gas), increases in productivity (coal), and changes in extraction technology (metals), all of which topics are discussed in the commodity chapters.

There have been shifts in the distribution of mining and energy employment among the four RPA Regions during the period 1978-1990. During the period 1978-1990, the Rocky Mountain Region accounted on average for almost two-thirds of U.S. metal mining employment; the North Region accounted on average for almost 30%, and the Pacific Coast Region accounted for the remaining 6.5% (figure IICiii-2).

The South Region accounted on average for almost half of U.S. nonmetallic mineral mining employment over the period 1978-1990; the North Region rose from 19% to 35% of the total during this same period, and the Pacific Coast Region declined from 31% to 19% during this period. The Rocky Mountain Region was responsible for the remaining 4%

[22]RPA regions were not created with mineral production in mind. In a number of instances mining districts or oil fields that extend across state borders are split between 2 RPA regions. For this reason, RPA regional product is given less emphasis here than is GSP.

in the three recent years 1988-1990. Nonmetallic mineral mining employment in the Rocky Mountain Region has been almost stationary from 1988 to 1990, the only years that have been reported. This accounts for the fact that Rocky Mountain employment for this sector is only shown for three columns on figure IICiii-3.

Real hourly wages for all private jobs fairly consistent over the 1978-1993 period (figure IICiii-4, table IICiii-2). Total industrial wages were lowest for the 14 year period in 1991 ($7.41/hr). The high occurred in 1978 ($7.88/hr), but was only 6.5 % higher than the low. Wages in the extractive industries were more variable and consistently higher by comparison.

As of 1993, the real average wage in nonmetallic mining was $8.71/hr, in oil and gas $9.70/hr, metal mining $10.49/hr and coal $11.84/hr (in constant 1982 $s). Real wages in the oil and gas, coal, metallic and nonmetallic mining industries all rose during the 14 year period, but declined to near or below 1977 levels by 1993.

Total employment in the energy and minerals industries was approximately 711 thousand in 1990, less than 1 % of total U.S. employment. Nonetheless, jobs and income generated by these sectors are of real economic importance to the economy. As noted above, earnings in these industries are high relative to average industrial or agricultural wages. Mining or oil industry jobs represent an important source of income in many rural areas.

INTERNATIONAL ASPECTS AND NET IMPORT RELIANCE

The energy and minerals industries are truly international in several respects. Firstly, many major oil and mining companies are multinational in nature, with subsidiaries, joint ventures, producing operations and exploration activities around the world. For example, Chevron produces oil off the coast of Angola as well as in the United States and other countries; Toronto-based Barrick Gold Resources Corp. produces gold in Nevada; Kennecott Corp., a subsidiary of London-based RTZ Corp., is part owner of the Colowyo Coal Co. in northwestern Colorado; and Cyprus Amax Co. of Colorado operates mines in Chile, Peru, the United States and other countries.

Secondly, most energy and mineral resources are traded inter-regionally, often in well organized international markets such as the London Metal Exchange. Several characteristics of energy and mineral resources affect the magnitude and extent of trade. Ubiquity of deposition is perhaps the most important quantitative factor affecting trade or the lack thereof. Deposits of some minerals, such as gravel, are quite common, precluding the need for interregional shipments. Some resources, such as platinum group metals and lithium, are found in relatively few inter-regional geographic areas so trade is necessary.

Another variable impacting the level of resource trade is the weight to value ratio. Minerals with a high weight to value ratio are less often traded over long distances than are those with low ratios, since the cost of freight could exceed the sale price of the resource. Conversely, a low ratio increases the likelihood that international trade would be profitable. Thus diamonds are traded in world markets and transported by air, whereas sand is traded intra-regionally and shipped by truck or perhaps rail.

In other cases, the resource may be available in many areas, but high quality deposits with low extraction costs dominate the market worldwide. For example, iron ore has been mined in many locations around the world, but Brazilian iron ore currently competes successfully in most areas of the world, including the Japanese markets. Alternatively, resources may be traded because production from different deposits is of differing quality or composition. The almost pure white Carrara marble from Italy is exported to countries all over the world because of its unique characteristics. All

[23]Value here refers to market price, which is affected by supply. The availability of large supplies of a resource will drive down price, ceteris parabus.

energy resources, except for geothermal, are traded, reflecting the high levels of international demand, as well as differing quality and costs of production.

Finally, it should be noted that a large percentage of mineral commodities are consumed by industrialized nations like the United States, Japan, and the European Community, although they are not necessarily produced in those countries. Figure IID-1 shows the share of mineral consumption filled by imports for the major industrialized countries/regions. However, all countries are to some degree dependent on the import of minerals. Security of supply for these essential imports depends on political, economic, and technical factors that differ by resource and country of origin (or destination.)

Many of the energy and mineral resources used by industrialized societies are imported from developing nations, some with fragile economies and unstable governments. For many countries, the production of minerals is a driving force in their nation's economy. Mining provides employment for citizens, revenue to the state in the form of taxes and, for those countries which are major traders in materials, provides a valuable source of hard currency. Unfortunately, there is a low correlation between the production and export of a mineral endowment and widespread economic prosperity in many developing countries (Tilton 1992). This failure of resource development to raise standards of living may have implications for the future stability of resource supply from some regions of the world.

Resource firms will explore for energy and mineral materials wherever there are favorable geological, political and social conditions. Ample funding is available internationally for well conceived development projects with high probabilities of success; lack of currently available infrastructure is rarely a deterrent when other factors are positive. Some countries have encouraged investment of foreign capital with favorable tax laws and assurances of repatriation of profits and capital and security of land tenure. However, political or social unrest can undermine these promises. Some countries have imposed strict controls and even expropriated mining properties, although these types of actions are less common than they once were.

We turn our focus now to the trade situation for the indicator energy and mineral resources, each of which will be considered in turn. Tables IID1-11 report domestic primary production as a percent of world production, exports and

[24]Additional information on each resource, including major producers worldwide, can be found in the commodity chapters of this report.

imports of primary product, and net import reliance.

In the case of chromium, the U.S. has always been a net importer (table IID-1). No chromite ore is mined domestically. Import reliance is not 100% because some of apparent consumption is fulfilled through reprocessing of chromite containing materials and removals from stockpiles. Nonetheless, the U.S. ultimately requires imports of this resource, which is essential for the production of stainless and alloy steel. Major producers include South Africa, the former Soviet Union, Albania, Turkey, India and Zimbabwe, which together account for over 85% of world production. Disruption of international trade or significant decreases in production in one of these countries could lead to increased interest in exploration for and development of domestic chromium resources. Chromium is a locatable mineral on Public Domain lands, and a leasable mineral on Acquired lands. Exploration could lead to discoveries and eventual mineral development on public lands; however, it is unlikely that the United States could become self sufficient in the production of this resource.

The United States consistently produced between 14% and 20% of the world's copper during the 1977 to 1990 period and is currently second only to Chile in mine production (table IID-2). We both import and export refined copper and in most years have a positive net import reliance, i.e., we are net importers of copper. The reported U.S. reserve and reserve base for copper are exceeded in magnitude only by those of Chile. Additions to domestic reserves have decreased in recent years, however. Production costs at Chilean operations are on average less than those for the U.S., suggesting that future domestic developments may emphasize deposits amenable to lower cost, solution mining techniques. Deposits of this type have been identified in several parts of the country, including on lands within the administrative borders of the NFS. Thus, pressure to develop copper resources on public lands is more likely to be driven by relative cost considerations than by shortages caused by the disruption of international trade. Copper is a locatable mineral on Public Domain lands, and a leasable mineral on Acquired lands.

Domestic consumption of gold for industrial and decorative purposes could easily be fulfilled from domestic production. However, these uses are dominated by demand for gold from the investor/financial sector of the economy. International trade in this commodity could be affected by changes in the world economy (a return to the gold standard by the major industrial nations, for example), the financial concerns of an individual nation (i.e., sales from a national

[25]This country has no chromium reserves, only reserve base and resources.

stockpile to earn hard currency), or by major new discoveries that resulted in low cost supplies being offered for sale in international markets. Since 1977 the U.S. has moved from a net import reliance of 61% to being a net exporter of gold bullion (table IID-3). Gold production has also increased in other parts of the world. Within the U.S., gold is a locatable mineral on Public Domain lands, and a leasable mineral on Acquired lands. Many of the domestic gold mines developed in the past 25 years have been on public lands (or on lands that were within the Public Domain, but were subsequently taken to patent.) To the degree that gold remains a desirable commodity, continues to be viewed as a "store of value," and the price remains over $200/oz, exploration for and production of gold in the U.S. will probably continue at its present high level.

Lead reserves and resources exist, and the commodity is mined, in many countries around the world. Lead is often produced as a co- or by-product of the production of other metals, particularly zinc and silver. The U.S. is a net importer of lead, but has extensive reserves and together with Australia fully one half of the reported reserve base (table IID-4). A pollution prevention measure known as source reduction penalizes the use of virgin lead in manufacture and encourages recycling. This and other environmental regulations directed toward lead could have the effect of dampening exploration and development activity for this metal in the U.S. and of altering the form in which lead is imported into the United States.

The United States remains a net exporter of molybdenum (table IID-5). This country contains almost of all reported reserves and reserve base for this metal. Trade patterns could be altered by the discovery and development of major new low cost reserves in another country. Nonetheless, the U.S. is self sufficient in molybdenum and would suffer only the loss of export earnings should trade be disrupted, which is unlikely.

The United States has historically been a net exporter of phosphate rock (table IID-6). Only Morocco and the Western Sahara, South Africa, and the former Soviet Union report higher reserves and reserve base than does the U.S. The extensive reserves in Florida and North Carolina ensure that domestic supply is secure. Export levels may decrease over time, but it is unlikely that the U.S. would become a net importer of phosphate in the foreseeable future.

Unlike the case discussed above, the United States depends upon imports of platinum group metals (PGM's) for a large proportion of supply (IID-7). There is only one producing PGM operation in the U.S., with the balance of supply being imported. The largest producers in the world are South Africa and the former Soviet Union, followed at a distance

by Canada and the U.S. Should trade be disrupted, production from the Stillwater Mine in Montana could not fulfill domestic requirements. PGM's are locatable minerals on Public Domain lands and leasable minerals on Acquired lands in the U.S.

Net import reliance for zinc has consistently been in the range of 60% (table IID-8). The United States has extensive reserves and is a producer, but continues to import ore, concentrates, and metal. Leading producers include Canada, Australia, the former Soviet Union, and Peru. About 60% of zinc metal, concentrate, and compound imports come from Canada and Mexico so the potential for supply disruption is low.

The United States is heavily dependent on imports of petroleum and petroleum products (table IID-9). Imports and import reliance dropped after the oil shocks of the 1970's, but in recent years have steadily grown. With domestic exploration and drilling programs shrinking, expectations for oil independence are low. The effects of a trade disruption could be significant, based on the experience of the Oil Embargo of 1973. Real prices of oil to users increased by 1%/year between 1963 and 1973, but jumped 11%/year between 1973 and 1979 (Nordhaus 1980). The quantitative effects of that embargo included inflation, increased fuel prices overall as coal and gas prices rose in sympathy with oil, and a transfer of real income from OECD countries to OPEC equaling approximately 2% of OECD GNP (Llewelwyn 1983.) Disruption would undoubtedly lead to increased interest in domestic production and potentially to more exploration and drilling on public lands, where extensive resources are believed to exist.

The United States has extensive natural gas reserves and resources. Although the nation is a net importer (table IID-10), the potential exists for import independence. Increased natural gas usage for electricity generation and as vehicle fuel has been encouraged due to the clean burning properties of this hydrocarbon. Increased exploration and production activity on both public and private lands is possible, particularly if energy independence is set as a national priority.

Extensive coal reserves and resources exist to support domestic needs for many years, certainly past the 50 year time horizon of this report. In fact, the United States is a major coal exporter (table IID-11). Disruption of trade or production in another part of the world could lead to increased demand for and thus increased exports of U.S. coal.

ENERGY AND MINERAL INDUSTRY TECHNOLOGY

Energy and mineral activities progress through four stages: exploration, development, production and

reclamation. A brief introduction to the standard technologies and methods utilized at each stage is provided for mining. Petroleum production is also reviewed. Statistics on exploration, development, and production activity levels, as well as typical capital costs are reported. Issues related to reclamation and technological advances are also discussed.

Mineral Production Path

Exploration entails locating economically recoverable reserves of a mineral and ascertaining physical and chemical characteristics of the deposit. A typical exploration effort would have several phases, such as those described below:

- review the literature on geology, previous discoveries, surface and mineral ownership patterns and access routes to the area;
- conduct a geological reconnaissance to select location(s) for detailed geologic study;
- obtain permits and permission to conduct drill hole sampling;
- conduct exploratory drilling;
- analyze drill hole samples.

Exploration Techniques

Perhaps the most fundamental step in exploration is understanding the geology of the ore deposit and its geologic setting. Geologic maps and cross sections portray the rock types (e.g., sandstone or shale), formations (e.g., the Morrison) and structure (e.g., faults and folds of the region. They are developed and refined as new information becomes available. The level of detail portrayed reflects both the level of information available and the needs of the user. During the initial prospecting phase, the maps will be regional in scale and will be fairly general. As exploration proceeds toward development, the maps and cross sections will reflect the greater need for detail.

Geochemical exploration involves trace metal analysis of air, water, soil, and rocks, with the goal of isolating the element of interest. However, the intent of geochemical exploration can also be to locate elements that are indicators of a

potential mineral deposit rather than to locate the mineral elements of the deposit itself. Specific associations of elements can also be indicators of deposits.

Rock chips are analyzed in the hope of identifying patterns of trace element occurrence. Soils are examined because they are a weathered representation of the parent bedrock below. Trace element studies of plants may be conducted to determine if unusual concentrations of minerals exist.

Geophysical exploration is possible because some ore deposits contain minerals that possess measurable physical characteristics. These include density, magnetic behavior, electrical conductivity, and radioactivity. The methods utilized to measure these characteristics are gravity, seismic, magnetic, electromagnetic, electric, and radiometric. All these methods are important for metals exploration, with the exception of gravity and seismic, which are applied almost exclusively to oil, gas, and sulfur exploration and are discussed later in this chapter.

Trenching, pitting and over burden drilling are intended to expose the underlying rock to facilitate other exploration techniques. Small scale activities would include shallow pits or backhoe trenches. Larger scale activities may require development of an exploration shaft, up to 100 feet in depth, or trenches dug with large bulldozers.

The primary purpose of exploration drilling is to determine whether a potential mineral deposit exists. If so, drilling will facilitate preliminary estimation of size and grade (for mining) or estimation of specific gravity and other characteristics for oil. Another important objective is to further define the subsurface geologic conditions. The three most common methods for mining exploration drilling are percussion, rotary and diamond. These differ in the method used to cut the rock. In addition to these, there is of course hand drilling, which has limited application in modern exploration.

Once a deposit has been identified and defined through use of the aforementioned exploration techniques, there is a need for information to further define grade and choice of metallurgical method. Bulk samples of the ore are collected and used in pilot tests of concentration methods.

The Bureau of Mines collects data on mineral exploration and reports levels of activity in terms of thousands of feet (Table IIEi-1). Exploration activity for metals has decreased significantly since the late 1970's. Exploration activity for nonmetals has decreased since 1978, but not the degree that has been the case in the metals sector. As figure IIEi-1

[26]Grade refers to the percent of desirable material, i.e., ore, present in the deposit.

illustrates, Rocky Mountain states dominated mineral exploration activities during the 1982-1987 period.

Review of expenditures on exploration activities provides another perspective. Table IIEi-2 reports capitalized expenditures on mineral exploration and development, and mineral land and rights, for 1977, 1982 and 1987 in 1982 dollars. Table IIEi-3 reports expensed expenditures for the same categories and time periods. Capitalized exploration and development includes expenditures on exploration and development at producing mines, but not buildings or machinery. As Crowson (1988 p.63)) points out, "much successful exploration would appear under this heading. Expensed exploration and development in the table includes most unsuccessful exploration and the amount of successful exploration and development expenditure that companies are prepared to write off against annual profits." The tables clearly show the decrease in exploration activity for most categories since 1977.

Project Feasibility and Development

At a stage late in the exploration process, but prior to development, feasibility studies will be conducted for the proposed mineral project. The purpose of these studies is to determine whether the deposit can be developed and extracted at a profit. They can be thought of as having 2 basic parts, geology/engineering and economics. The resource and engineering details to be considered would include, but are not limited to, deposit resource and grade, mill recovery and concentrate grade, mine/mill production level, and environmental compliance requirements. The economic parameters to be considered would include cost of capital, cost and type of financing, expected rate of return, necessary working capital, operating costs, tax regimes, and expected selling price for product(s). Analyses would be conducted to determine the expected rate of return for the project under a variety of scenarios. A viable project would probably need a nominal return of at least 15 percent.

The feasibility study will include preliminary selection of mining, milling, and reclamation methods and production levels. The mining method will be determined by a number of important criteria, including size and shape of the ore body (e.g., vein or disseminated), depth to mineralization, topography, and the geologic characteristics of the ore body and surrounding rock (e.g., faulting and folding). The beneficiation method selected for the associated mill will

[27] The Dept. of Commerce collects these data only every 5 years.

depend upon the physical characteristics of the ore, including hardness, density, and grain size. The grade of the ore and all accompanying recoverable and nonrecoverable constituents will also directly influence selection of beneficiation methods(s). Feasibility and cost of reclamation will affects technical decisions.

The size of the operation will be determined by 2 closely interrelated factors, engineering efficiency and cost minimization. The overriding goal of the firm is to produce output at the minimum cost per unit; however, this will be limited by technical factors. Production levels at mining/milling operations are constrained by the type of mining or processing method being used and the equipment related to that method. This is most apparent in beneficiation plants where each unit operation has a maximum "turndown ratio" which defines the lower limit for production capacity for that unit while maintaining quality of the output. The unit with the highest "turndown ratio" defines the lower limit for that whole mill. Materials handling equipment, such as pumps, conveyers, and surge capacity, may only be able to operate at one rate.

If the feasibility study indicates that the project would not be economically viable given current engineering and economic parameters, development would normally not proceed. If on the other hand, the feasibility and engineering analyses indicated that the project could be profitable, then a decision regarding development would need to be made. It should be noted that not all projects reaching this stage are developed, regardless of their economics, due to other social, political and environmental factors.

Assuming a decision to develop is made, the following actions will take place. Financing for the project will be acquired, including loans, partnerships, and joint ventures. A program of developmental drilling will be initiated, with the goal of better defining the ore body. Infrastructure not already in place, i.e., roads, power lines, water supply, rail spurs and potentially temporary housing, will be constructed. The next stage will be construction of mine (underground, surface or leach) and mill facilities.

Table IIEi-4 reports mine development activity in the United States for selected years in terms of the feet of shaft and winze sinking, raising, drifting, crosscutting, and tunnelling, and solution mining accomplished in each year. Metal development activity followed a pattern similar that of exploration, a significant drop after 1980 followed by a slight recovery in 1989 and another drop thereafter. Conversely, development of nonmetallic minerals has been variable over the entire period.

Mining Techniques

The purpose of mining is to remove ore from the earth. Mining can be classified into 2 types, underground and surface. In either case, surface facilities to house maintenance, personnel and administration services are necessary. In addition, both underground and surface mines require initial mine development. For underground mines, this includes developmental shafts and adits and for surface mines, stripping off and storage of top soil. Preparation for the mill site take place concurrently.

Underground mining methods are selected primarily because the depth of the ore body from the surface makes surface mining methods infeasible. The selection of underground mining method is based on a variety of factors, including: size and shape of ore body, overburden conditions, strength of ore and surrounding rock, water factors, cut off grade. An ore body might be mined initially using surface techniques, with the operation eventually switching to underground methods. Alternatively, surface and underground mining could take place concurrently, as is the case at the Climax Molybdenum Mine in Colorado.

Most underground mineral mining falls into the category of stoping, which is defined as follows. "The act of excavating ore, either above or below a level, in a series of steps. In its broadest sense stoping means the act of excavating ore by means of a series of horizontal, vertical, or inclined workings in veins or large, irregular bodies of ore, or by rooms in flat deposits." (USDI, Bureau of Mines 1936, p. 3.)

The five most common stoping methods are open, shrinkage, cut and fill, square-set stoping, and block caving. An open stope is one for which no supporting pillars are required. In shrinkage stoping the ore is broken on one level and dropped to a lower level for removal from the mine. The mine is worked from beneath the ore zone, with miners standing on previous broken ore and working up through the ore body. Cut and fill stoping is similar to shrinkage stoping, except that waste rock is left in the mine to support the walls and to serve as a platform for miners. Square set stoping is selected when the ore is weak and the walls are not strong enough to support themselves. A block of ore is removed and the area immediately timbered. Block caving is used to extract massive ore bodies, where surface collapse will not be a problem, since removal of the entire ore body may cause a large depression at the surface.

Ore and waste rock are removed from underground mines in 2 direction. Where possible, ore is removed horizontally through an adit via trucks, trains or conveyor belts. Alternatively, the ore will be hoisted to the surface through a shaft. Nearly all underground mines have shafts, whether used for hosting, ventilation, utilities, or personnel movement.

In underground coal mining operations, the seam is extracted with limited surface disturbance, although surface subsidence over the mined area after years of settling is of increasing concern. The extraction process is conducted below the surface and access to the coal deposit is obtained by one of three methods: drift, slope, or shaft.

Topography, type of coal bearing formation, and depth of coal deposit determine the type of access opening to be used. Coal outcrops in hills or mountains are generally entered by the drift method (horizontal tunneling) provided the seam does not dip greatly or have a great pitch. If an outcrop does not occur but can still be accessed by downward sloping tunneling, a slope opening is used to gain access to the coal seam. The vertical shaft method is used primarily for very deep mines and where the drift and slope methods are not feasible. A typical U.S. shaft coal mine is 250-300 feet deep although coal seams are accessed by much deeper shaft entries in Europe. Material must be hoisted to the surface by elevator(s), which is the least efficient and most expensive method of handling bulk material.

The room and pillar mining method has been used longer than any other method for mining coal in the US. As mining advances, rooms are excavated in the coal seam and the strata above are supported by the remaining pillars left in place. Additional supporting mechanisms such as roof bolts, roof trusses, yieldable arches, reinforced concrete lines, and wood or steel sets are required depending on the nature and condition of the overlying strata. Mechanized room and pillar mining is conducted by the use of either a conventional mining system or a continuous mining system. Conventional mining is the older of the two and until about 1950 was the primary method used. Since that time, the continuous mining technique has rapidly replaced the conventional mining system.

In room and pillar mining the entire thickness of the coal seam is mined. Under these conditions, the recovery rate (coal mined as a proportion of the total coal in the seam) can be as high as 50 percent. The coal which is left in the pillars is used to support the roof (overburden) above the rooms which have been mined. However, it is often necessary to leave part of the coal seam above the rooms for additional roof support.

Where surface subsidence is permissible or where mining operations are so deep that mine cave-ins will not

dramatically alter the surface terrain above the mined out area, the coal which has been left in the pillars for support can be extracted by a retreat mining method.

Longwall mining, first introduced to the United States in the 1950's, has been used extensively in Europe. The longwall machine laterally shears or plows coal along the length of the face, transports the fallen coal by an advancing conveyor to a secondary haulage conveyor, reverses direction at the end of a cut, and supports the roof in the area of the face by a self-advancing system of hydraulic jacks. The roof is then allowed to cave-in behind the advancing work area or blasted to insure a controlled cave-in rate and to reduce overburden pressure on the coal seam face being mined.

Surface mining methods are selected whenever possible because they tend to be less costly than underground mining methods. The cost efficiencies of surface mining techniques allow lower grade ore bodies to be exploited. The most common forms of surface mining are placer, open pit, strip mining, auger, and heap leaching.

Placer mining is selected when concentrations of heavy minerals in alluvium can be easily removed and washed. There are three types of placer mining; panning/sluicing, hydraulic mining, and dredging. Panning involves hand washing of the alluvium to removal of the metal. Because of the slow, labor intensive nature of this activity, panning has become restricted to recreational activity in the United States today. In sluicing, alluvium is shoveled into a sluice box, through which water is directed. The metal caught is a series of riffles as the water washes the waste away. Sluicing is similarly uneconomic for almost all ore bodies today.

Hydraulic mining is seldom permitted in the United States due to the magnitude of the land disturbance it causes. A powerful jet of water is used to cave in and wash away an alluvial deposit. The broken material flows through sluice boxes and on into an adjacent stream or body of water. Within the placer category, dredging is the most commonly used method today. Floating dredges are used to either scoop or suck alluvial material off the bottom or from the edges of a natural or artificial body of water. A wash plant often floats directly behind the dredge to facilitate the first stage of concentration.

Open pit mining is one of the most common types of surface mining in the United States and worldwide. Although large open pit mines appear simple in concept, they are actually expensive to develop. Surface waste material (i.e., material that is not considered ore) must be removed to reach the underlying deposit. The deeper the pit, the wider the opening at the top and thus the more expensive the mine. Careful engineering design is required to maximize

extraction of the ore while at the same time minimizing removal of waste material. The ultimate size of the mine will be determined by a combination of the ore to waste ratio, the cost of moving material and the grade of the ore. The walls of the pit are inclined and broken into a series of benches. These typically spiral from the surface to the bottom of the mine providing continuous access. The benches define the working faces of the mine. It is there that ore is blasted, as well as drilled. Ore and waste are usually removed from the pit via truck, with rail and conveyor belts sometimes being used. The use of this type of mining to extract coal has been tried on seams where numerous pitching seams lie parallel to each other and where outcrops are on relatively flat terrain. The overburden can be removed by either scrapers or shovels loading into trucks.

Strip mining methods are used when a deposit is bedded, tabular (i.e., flat and thick with one bed lying on top of another), and sedimentary. In the United States it is the predominant surfacing mining method for coal and phosphate. Most commonly, the soil and overburden are stripped from an initial cut and stockpiled. The ore is excavated, while a second parallel cut is stripped of overburden. The waste from the second cut is side-cast into the first cut. This cycle is repeated as the mining proceeds. Transport in coal mines is typically handled with very large trucks, while in phosphate mines the material is slurried and pumped through a pipeline to the beneficiation plant.

The auger method of mining coal entails boring horizontal or near horizontal holes in the exposed coal seam face and loading the coal removed by the auger. Auger mining is generally used as a supplementary recovery method operated in conjunction with contour strip mines when the overburden thickness becomes too great to extract the coal economically by other methods. It is also used where the terrain is too steep for overburden removal and where recovery by underground mining methods would be impractical or unsafe. Augering is considered to be a method of recovering part of a coal seam that would otherwise not have been mined. Auger mining can also be used to recover coal between abandoned underground mines and adjacent strip mines in areas where a weak roof would prevent underground mining and where thick overlying sandstone would necessitate difficult and expensive drilling and blasting if strip mining was used.

Leaching operations combine some of the activities of mining with some from beneficiation. There are three types of leaching: in place, mining dump, and heap leaching. In the first case, ore is fractured in place with explosives and leachate solution is applied that draws desired metals into the solution. The pregnant solution is collected, the desired

constituents precipitated out and the leachate reapplied in a continuous cycle. In place leaching is much less expensive than conventional mining methods; however, it has not been widely applied since the environmental impacts and engineering parameters are not yet fully understood.

Mining dump leaching involves the reworking of waste material from surface or underground mines using leach methods to remove any remaining metal. The method is currently being successfully applied to copper and gold mine waste dumps. As a result, waste dumps at most new copper and gold mines are designed to accommodate leaching.

Heap leaching differs from the preceding 2 types of leaching largely in that virgin material is removed from the ground and piled on a lined pad for leaching rather than being leached in-place. Heap leaching is used on ores with grade too low to be profitably exploited using conventional mining and beneficiation methods. This method is most commonly applied to low grade copper, uranium and gold ores.

Beneficiation Methods

Beneficiation "is the mechanical separation of the grains of ore minerals from the worthless gangue. The resulting concentrate contains most of the ore minerals and the waste is called tailings" (USDA, Forest Service 1995). Beneficiation plants are usually located on the mine site or nearby. They are designed specifically to treat the ore of that particular deposit or a blend from various local deposits. Beneficiation proceeds in stages. The first stage, if necessary, is crushing. Crushing and screening are used to provide size consistency and to remove large pieces of foreign material. Crushing and screening are usually done with a breaker. Cleaning of coal, commonly referred to as washing, is required if more refinement is necessary. This method is used primarily to remove sulfur from coal and is done either by air washing or wet washing.

There are usually 2 steps to the crushing process, primary and secondary, which are intended to reduce the grain size to that needed for subsequent processing and to insure uniformity in the feed. Occasionally, a third grinding step is added if very fine grain size is required. Also, the washing/screening stage may be included to separate the coarser material from the fines.

The second stage of beneficiation involves the physical liberation of the desired mineral(s) from the ore. The

three most important separation methods are: flotation, gravity, magnetic. In floatation, the ground material is mixed with various reagents and water and then agitated with paddles or injected air. The desired minerals attach to air bubbles that are then scraped off as they rise to the surface. Several selective stages of flotation may take place. The remaining material and liquids are pumped to tailings ponds. Gravity separation takes advantage of the fact that the desired ore minerals are heavier than the gangue. The ground material is agitated on sloped tables, jigs, or spirals, or in liquid, so as to separate the heavier mineral material from the lighter.

The third separation method takes advantage of a different physical property, magnetism. Ores exhibiting this property are separated by moving a wet or dry stream of ground material past a magnetic cross belt, bar or drum. Some 20 ores can be processed with magnetic separation, the most common being iron ore.

Mine Wastes

Mine wastes are generated by all mining methods. Disposal of the waste material is a major consideration in the mine operation and design. These wastes may either be returned to the mine or reside in mine dumps. Surface mining methods result in far greater amounts of waste than do underground mining methods. For surface mines, the ratio of waste to ore commonly exceeds 1:1 and may even reach 10:1 for some larger mines. The ratio for underground mines is usually less than 1:1.

Mill wastes are called tailings. They have as constituents the gangue material, plus the reagents and liquids utilized in the beneficiation process. These wastes are stored in ponds or may be partially dewatered and pumped back into abandoned stopes. The volume of tailings to concentrate is always quite high because ores normally contain a very small percent of desired material. For example, low grade copper ores contain only 2 or 3 percent copper by weight; the remaining 97 or 98 percent of each ton of ore ends up as tailings.

Frequency of Occurrence and Capital Costs for Various Mining Methods

Table IIEi-5 lists the number of domestic producing operations for metals and nonmetals, organized by mining

method and RPA region (USDI, Bureau of Mines 1995). As of 1995, there were 1,755 active metal and 18,776 active nonmetal mines in the United States. It should be noted that many of these are small operations; the number of major mines is much smaller. Precious metals are heavily represented, with 702 mines listing gold as the primary product. In addition, there are almost 250 iron mines, 230 silicon mines, and 180 copper mines. There are probably more nonmetal mines than reported by the Bureau of Mines due to the fact that their data base does not include a complete record of active sand and gravel operations.

Slightly more than half of the metal mines utilize surface mining methods, whereas the vast majority of the nonmetal mines are surface operations. In all cases combined operations are less common than either surface or underground. In addition, only a few mines are currently using leach methods.

Over 60% of the active metal mines are in the Rocky Mountain region. Nonmetal mines are spread across all four regions, although more than a third of the total can be found in the Northern region.

The number of major producing mines in the United States has decreased for several important minerals, as well as for coal (Table IIEi-6). Between 1981 and 1991, the number of major copper mines decreased from 25 to 17, molybdenum from 5 to 1, and phosphate from 34 to 25. One platinum operation did open during the period. These results are consistent with the expenditures and activity levels for exploration and development that showed dramatic decreases.

The only metallic mineral enjoying an increase in activity is gold (Table IIEi-7). Three trends are reflected in the data. First, significantly more gold was being produced domestically in 1990 than was the case in 1982, a trend which has continued. Secondly, gold production is no longer dominated by the top 25 producing mines. Finally, there is a shift from placer to lode deposit mining. Approximately 70 major new lode gold mines have been opened since 1982 and 8 of the 19 lode gold mines in the top 25 in 1982 have since shut down.

As noted in table IIEi-6, the number of surface and underground coal mines has decreased. Each major mining method has benefits and problems. Underground mining has the advantage of allowing extraction of deep seams; however, the method also has disadvantages related to worker safety and environmental protection (table IIEi-8). Surface mining has pluses and minuses as well. Nonetheless, production from surface operations has exceeded that from underground since the early 1970's (figure IIEi-2).

Mines and beneficiation plants for most minerals are enormously expensive to develop (Table IIEi-9). A typical new copper mine, whether surface or underground, costs $248 million to build (in constant 1982 dollars). A new strip mine to extract phosphate ore would cost an estimated $145 million. A new coal mine could potentially cost between $75 and $200 million or more (Reisinger 1993). The average capital cost per metric ton of contained gold for heap leach operations is $805.50. The cost per ton for mines using traditional beneficiation methods is 80% higher. Under the circumstances, it is not surprising that most new gold mines use heap leach methodology, a trend previously identified in the mine construction data. There is shift toward solvent extraction in the copper industry as well. Permitting, design and construction of a new facility can take up to 10 years, particularly for large operations or those in environmentally sensitive areas. As a result, these expenditures must be made years in advance of any expected revenue.

Mine Reclamation

The field of Mine Land Reclamation developed only recently, in response to both public and private concerns that the unmitigated impacts of mining were causing serious environmental damage. Prior to the 1970's, reclamation of mine sites was not required and consequently was not performed for the majority of mines; whereas now reclamation is the norm, rather than the exception.

During the past twenty years, reclamation of mined land has evolved from a process based on trial and error to a science with established methods and measurements of success. The field encompasses many disciplines, with contributions from agronomy, botany, range science, soil science, and agricultural and environmental engineering, among others (Reith 1986).

[28] Capital costs are distinguished from fixed and variable costs because they generally appear on the income and balance sheet statements (capitalized expense deductions such as depreciation of long term assets and intermediate or long term assets, respectively) rather than on the cost of goods statements for accounting purposes. The term "capital costs" is frequently used in two contexts. Capital costs may refer to initial investment in assets necessary to generate production. Capital costs may also refer to "financial capital" such as debt and equity financing which appears on the right hand side of the balance sheet such as liabilities and equity.

Reclamation is generally understood as rehabilitating the land. The intent is to control erosion, restore hydrologic balance and to limit the off-site impacts during and after mining. Post-mining the site should be capable of supporting activities at least as beneficial as those taking place before extraction (National Research Council 1979). Thus, the ultimate goal of reclamation is to restore the mining site to productive use for agriculture, forestry, wildlife habitat, housing and/or recreation.

Significant advances have been made in the areas of plant species selection and establishment, soil storage and reconstruction, plus mine waste disposal and containment. Acid mine drainage (AMD) is still a serious environmental hazard, but the causes are now fairly well understood and AMD can usually be prevented. Cost effective solutions for controlling AMD, such as biological wetlands, are also beginning to show promise. Methods for storing mine waste in mined-out underground shafts are currently being explored internationally. These developments, plus alternative uses for post-mine sites, highlight some of the current reclamation research.

The section is organized in the following manner. Initially, statistics on the area of land utilized for mining land still in need of restoration will be presented. This is followed by reclamation techniques, mill tailings, and leached ore piles for underground and surface mines. Finally, a discussion of general factors affecting reclamation success and technical advances is presented. (Oil and gas well reclamation is discussed at the end of the Petroleum Production section.)

Land Reclaimed

The exact amount of land temporarily or permanently dedicated to mining activities is unknown. Land usage and reclamation estimates for the 1930-1971 period were published in 1978 by the Bureau of Mines (Paone et al.) and updated in 1982 (Johnson and Paone) (table IIEi-10). They have not been updated since that time.

The earlier report segregates land use by type of activity (rows) and type of commodity (columns). The latter report includes only row and column totals. During the 1971 to 1980 period the amount of land utilized for nonmetal and fossil fuel mining increased 51% and 80% respectively. As of 1980 8.1% of land used for metal mining and 27% land utilized for nonmetal mining had been reclaimed, compared to 72.9% of land mined for fossil fuels. Nonetheless, only .25% of the land area of the United States had been used for mining, of which 47.4% had been reclaimed. This compares

[29] The reason for the reported decline in land used for metal mining between 1971 and 1980 is unknown.

to 9.6% allocated to national parks, refuges, and wilderness, 3% to urban uses, and 70% to agriculture, as of 1980 (Dorr 1987).

Data from the Soil Conservation Service (now the Natural Resources Conservation Service or NRCS) provide an alternative perspective (Holmberg 1977). Table IIEi-11 reports 1977 state level estimates (aggregated from county data) of total hectares disturbed by surface mining. The total is broken into 3 status types (land not requiring reclamation, land needing reclamation that is not legally required, and land needing reclamation that is legally required) and 3 commodity types (coal, sand and gravel, all other). Neither the status nor commodity types are exactly comparable to Bureau of Mines categories. However, the 1977 NRCS estimate of the total area disturbed by surface mining (2,305,888 ha) is close to the 1980 Bureau of Mines estimate of land disturbance for all mining (2,307,692 ha).

According to the NRCS data, 33.2% of land disturbed by surface mining does not require reclamation. Of the remaining 1,540,268 ha's reclamation is legally required for only 443,041 ha's. It is reasonable to assume that reclamation has taken place on some part of the balance of the land, but statistics are unavailable.

Individual mines require varying amounts of land for varying lengths of time, depending upon the type of activity and the magnitude of the operation. World class mines may cover large areas. For example, Barrick Gold's Goldstrike property on the Carlin Trend in Nevada extends over 7,000 acres (28.3km^2) (White and Kral 1994). The Castle Mountain Mine in southern California, a recently permitted open pit gold mine, will cover about 2,700 acres, or about 4.2 square miles (USDI, Bureau of Land Management 1990). Most of the large open pit copper mines in Arizona and Utah cover a considerably larger acreage than Castle Mountain. Conversely, small open pit operations, such as a gravel mine, often require only a few acres of land.

Underground mines typically disturb less land than do surface mines, but yields per acre of land disturbed tend to be lower. For example, average coal production per acre disturbed has been estimated for 3 regions of the country (Peer Consultants 1984).

Region	Yield (tons/acre)
Appalachia	5,520
Interior	5,040
West	44,124

[30] These data were collected as part of the Rural Agriculture and Mining Program and have not been updated.

Underground mining is common in the Appalachian and Interior regions, where yields/acre are relatively lower, underground mining is common. The greater yield per acre in the west reflects the prevalence of strip mining in that area.

Reclamation of Underground Mines

Reclamation of underground mines differs substantially from surface mines. Most of the mining disturbance is beneath the land surface so there are substantially fewer acres to reclaim and revegetate. Underground mine land reclamation is primarily concerned with physical safety and prevention of surface and groundwater contamination (McElfish and Beier 1990).

Underground mines contain open mine shafts. Because they pose a danger to humans and animals openings should be covered and/or backfilled to prevent access. These shafts have either vertical or horizontal access depending on the location of the ore body. Mine shaft openings and constitute a serious problem; it is estimated that over 80,000 of these mines exist across the United States. There are a number of methods which can be used to seal off mine shafts. One approach is to fence off the shaft to prevent access and then permanently cover the shaft opening (McElfish and Beier 1990).

Covers and fencing are designed to prevent accidental entry, but will not protect against surface subsidence, which can cause damage to surface buildings plus prove dangerous to people and animals. Only shaft backfilling will provide support for shaft walls and prevent subsidence (USDI, Bureau of Land Management 1992). Shafts can simply be filled to the top with crushed rock, clay or concrete. Caps that are intended for permanent closure of vertical shafts should be constructed of reinforced concrete plus should be able to withstand the weight of the overburden. Horizontal shafts can be filled with rock and sealed with concrete, iron bars or roadway barriers (U.S. Congress Hearings 1990; McElfish and Beier 1990).

Mining firms are sometimes reluctant to refill shafts for business reasons. Either technological advances or market shifts could turn waste rock into ore, or make a previously uneconomic (and so shut down) mine profitable. If the waste rock had been returned to the shaft, it would be accessible without remining. Tailings and waste from underground mining operations, as well as acid mine drainage, will be covered under a separate section on Mine Waste Management.

Reclamation of Surface Mines

Reclamation techniques for surface mined land vary depending on the mineral being mined and the intended post-mine land use. In general, reclamation goals for large-scale surface operations are to return the land to productive use and prevent any adverse environmental impacts resulting from previous use.

Open pit mines normally create extremely large holes and this type of surface mine is the most difficult to reclaim due to the difficulty and cost involved in backfilling the pit. In active open pit mines the pit continues to expand and deepen throughout the mining process, making simultaneous reclamation impossible (National Research Council 1979). Pit reclamation can result in complete backfilling, partial backfilling, highwall slope reduction or a combination of these methods. The method chosen will depend upon the intended long-term land use, the mitigation of environmental impacts and the need to reduce the off-site impacts associated with waste and tailings disposal.

Once an open pit has been mined, it is generally not possible to replace all of the excavated material due to physical constraints. Broken rock has greater volume than solid rock; there is a "swell factor" of between 30 to 40 percent leading to excess waste material even after backfilling is complete (USDI, Bureau of Land Management 1992). The most notable advantage from pit backfilling is that the final landform most closely approximates the pre-disturbance conditions.

For large pit mines, which have operated for years, the actual pit is often not reclaimed due to the enormous costs of backfilling and reshaping (National Research Council 1979). In some instances, the pit will fill with water, creating an artificial lake. Depending upon the background geology, the water could be potable or contaminated with dissolved metals. Another consideration in not reclaiming the pit is the volatility of the mineral market. At some future date, it may be profitable to re-open a shut-down open pit mine as a result of an increase in the price of the mineral or a change in technology resulting in reduced operating costs.

Reclamation of Strip Mines

Many of the largest U.S. strip mines are found in the Western United States, although this type of surface mining is common in other parts of the country. These mines have a large impact on the environment because they annually disturb thousands of acres and produce many tons of overburden and other waste material (USDI, Geological Survey 1983). While a number of strip mined resources contribute to the total environmental disturbance, coal has the largest impact in terms of acreage disturbed and overburden produced (McElfish and Beier 1990). A great deal of the mined land reclamation research has focused on coal mines, as has legislation for regulating surface mines. Because many of the practices used to reclaim coal mines are common to other surface mined minerals, the following discussion of coal mines will serve as the example for large-scale strip mine reclamation.

Western strip operations are typically quite large, consisting of several hundred to several thousand acres. For most strip coal mines, reclamation is a continuing process tied into the mining cycle. Briefly, the process begins with scraping and storing of the topsoil from the area to be mined. As mining progresses, the material above the coal is removed (the overburden) and deposited as spoil piles in previously mined-out sections. Overburden which could be salvaged as a growing medium for revegetation may be separated and stockpiled. After the coal seam has been mined, overburden from new areas is deposited in the cut. These spoil piles are then graded, the stockpiled topsoil is reapplied and the areas revegetated. Appropriate species are seeded depending on the intended post-mine use, which for the majority of surface coal mined lands in the west, is either livestock grazing or wildlife habitat. One trait of surface coal mines is the large ratio of overburden to coal. Relatively thin coal seams are buried under up to several hundred feet of overburden (USDI, Geological Survey 1983). Thus, abundant material is available to fill in the mined-out areas.

Until 1977, and the enactment of SMCRA, reclamation was not required and therefore was not practiced by the surface coal mining industry. Early surface mines left the overburden as it was excavated in a series of spoil ridges with very steep slopes (McElfish and Beier 1990; U.S. Congress Hearings 1990). Excessive steepness of spoil slopes creates highly unstable soils which together with a lack of nutrient-rich topsoil makes plant establishment nearly impossible (USDI, Geological Survey 1983). This explains why surface coal mines which have been abandoned for decades often fail to revegetate naturally, especially in arid climates. Where moisture is plentiful, which greatly assists plant establishment, some abandoned mine sites have managed to overcome slope steepness and display good revegetative growth (USDI,

[31] See Environmental Legislation Section of this report for a complete explanation of the SMCRA Act.

Geological Survey 1983).

Reclamation of Construction Mineral Mines

Construction minerals of one type or another are the only mineral commodity produced in every state in the Union. This mineral group typically includes sand and gravel, crushed stone, limestone, gypsum and dolomite (Bauer 1991a). Construction mineral mines have several unique characteristics, which distinguishes them from other surface mines and affects the reclamation potential of post-mine sites.

Construction mineral mines typically have a longer life than other surface mines; average mine life is 82 years. Thus, there is usually a substantial time lapse between excavation and reclamation (National Research Council 1979). Mining these minerals generally creates a large excavation or hole. Most of the mineral deposit is utilized and the overburden volume produced is extremely low, so that local backfilling material is often unavailable. Consequently, backfill material would need to be transported to the site, usually at a significant cost. Because of these difficulties, construction mineral mines are frequently not backfilled. Reclamation for most construction mineral mines means conversion to a different land use, rather than restoration of the land to its pre-mine use unlikely (National Research Council 1979).

Construction mineral mines are usually located near urban areas because the mineral marketplace is the urban environment. Moreover, per unit transport costs for construction minerals are high relative to their sale price (Bauer 1991a). There is potential for redevelopment of mined-out construction mineral sites, because of the high demand for land near urban centers (Bauer 1991a). As cities and towns expand, undeveloped land becomes scarce. Construction mine sites have successfully been converted to sanitary landfills, lakes, industrial and residential building sites and wildlife refuges (National Research Council).

Mine and Mill Waste Management

The mining industry is second only to agriculture in producing solid waste. By 1972, thirty billion tons of waste

from non-coal mining alone had accumulated, covering an estimated 2 million acres. This waste estimate includes overburden and waste rock from mining plus tailings, slurries and slime from processing (National Research Council 1979).

Choice of waste disposal sites for both mining and processing wastes is governed by several factors, among them topography, chemical and physical properties of the waste, surface and ground water hydrology and post-mining land use (Hutchison and Ellison 1992). When reclaiming mine waste sites, the primary goals are to protect surface and ground water from pollution, plus restore the site to productive post-mine land use.

Mill tailings are among the most difficult mine wastes to reclaim, partly due to the volume produced (from 30,000 to 100,000 tons per day from a large mine) and partly due to the nature of the material. Tailings are composed of fine grained particles which can become airborne when dry and are physically unstable when wet (National Research Council 1979).

Water is usually a limiting factor in the revegetation of tailings. Infiltration rates are low, which combined with potential high surface temperatures, creates harsh growing conditions for plants (Hutchison and Ellison 1992). Treatment of tailings has been aimed at improving the growing conditions so that plants can become established. Applications of topsoil, organic matter in the form of sewage sludge and peat, plus fertilizers, have been added to tailings to improve water holding capacity, increase organic matter content and provide plant growth nutrients (National Research Council 1979). Where soil conditions are either too acidic or too alkaline, agricultural soil amendments can sometimes be added to neutralize soil toxicity (Hutchison and Ellison 1992).

Another factor which limits plant growth on tailings is the presence of heavy metals, which can prove toxic to plants. Heavy metals can be reduced through leaching. Water is applied to the tailings area or, in high precipitation zones, the site is allowed to lie fallow, allowing natural leaching of heavy metals (National Research Council 1979). Both of these approaches have the potential to exacerbate surface and ground water pollution. In such cases, it may be necessary to cap the tailings pile completely to prevent water infiltration.

Reclamation of Heap Leach Ore

Heap leaching is the process of metal extraction which involves trickling a solution through a pile of ore and then extracting the metal from the solution. While the extracting solution is continuously reused, the spent ore becomes waste and must be reclaimed like other mine waste piles (Hutchison and Ellison 1992). The most common way of handling the accumulation of spent ore is to use a dedicated or expandable pad where the ore is leached and simply left in place. Alternatively, leached ore can be removed and placed in a separate waste disposal area complete with leachate control and sediment collection (Hutchison and Ellison 1992). Leached ore may be left as is or may be capped and reseeded depending upon regulatory requirements, technical feasibility and cost.

Acid Mine Drainage

Acid Mine Drainage (AMD) is a major water pollution problem associated with many mines located in the United States. AMD can be found in both western states (where it is associated with metal mines) and in Pennsylvania, West Virginia, Maryland, Ohio, Illinois and eastern Tennessee and Kentucky (where it is largely the result of coal mining.) EPA regulations define AMD as drainage having a PH below 6 or a total iron concentration of 10mg/L. Decades of contaminated water supplies and the virtual sterilization of thousands of miles of streams by AMD from unreclaimed coal mines led to citizen pressure which helped pass SMCRA in 1977 (McElfish and Beier 1990).

One way to treat AMD is to divert the drainage into settling ponds where the water can be treated to precipitate the sulfides and metals. Additives that have been used to neutralize acid water include sodium hydroxide, sodium carbonate, calcium oxide, potassium hydroxide and various oxidizers, such as peroxide and sodium-calcium hyperchloride. These treatments produce a sludge which must be periodically removed for disposal. One disadvantage of these ponds as a long-term solution to AMD is that they are both labor and capital intensive, which may make operation costs prohibitive over time (McElfish and Beier 1990).

Acid Mine Drainage can also be neutralized by application of a blanket layer of limestone over the backfill material. Rainwater or snowmelt that contacts the limestone becomes mildly alkaline thus creating an alkaline "wetting-

[32]Causative factors for AMD are addressed in Chapter IIF in the section on Water Quality.

front" which acts to neutralize acid production. However, the amount of acid generated is generally greater than the bicarbonate produced so that the overall affect is negligible. Moreover, there is a delay of any benefit for 2 to 3 years.

Preventing water from flowing through a potentially acid generating medium will reduce the total acid load of the system. Plastic liners or other impervious materials such as clay or bentonite can be placed over spoil or backfill to prevent water infiltration. Soil can be placed over the top of the water barrier and then revegetated to stabilize the site.

Wetlands are naturally reducing environments where sulfates and other metals are removed from acid drainage. So far, wetlands are still experimental but show promise for treating mild to moderate acid drainage problems (McElfish and Beier 1990; USDI, Bureau of Mines 1991b). Where the drainage is highly acidic, wetlands alone cannot significantly increase the pH level, but can be used along with other chemical treatments. Also, the capacity of wetlands to neutralize acid may be somewhat limited over time. Wetlands may prove most useful for economical treatment of abandoned mine sites and low volume seeps than for highly acid drainage from new mines (McElfish and Beier 1990).

Bactericide can be added to backfill or spoil materials to kill the bacteria that catalyze the acid producing reactions (Caruccio et al. 1988). This method is useful when combined with other AMD treatments and since bactericide is water soluble, it must be repeated to be effective.

Recovery and sale of dissolved metals in AMD could potentially fund mine reclamation efforts. For example, metals recovered by EPA are being sold to pay for reclamation efforts at the Summitville Mine in CO (ref.). Also, it is estimated that by 2010, water in the Berkley pit of the Anaconda Co. (Butte, MT) will contain metals worth $700 million (E & MJ 1994).

Technological Advances in Mining and Mine Reclamation

The mining industry has been searching for better ways of extracting ore since mining began thousands of years ago. Originally, researchers were motivated by a desire to make mining safer and more profitable. These concerns are still important, but to them has been added the need to develop mining methods that are more environmentally benign and to successfully reclaim mined lands.

Minerals specific research is carried out by the Federal government (USDI, Geological Survey and Bureau of

Mines), universities and mining schools, and by private industry. Moreover, mining is a multi-disciplinary process. Advances in fields as diverse as mathematics, chemistry, and biology are adapted and applied to problems of mineral exploration and extraction. Research on mine design, including pit optimization, ventilation, and electrical systems, is continuous and the advances are incremental. There are however additional areas where important advances are being made. Computer applications and selective mining techniques will be highlighted here. Advanced computer applications in mining include robotics and geographic information systems. The objectives of introducing robotics in mining are threefold: improve the selectivity of rock cutting, decrease the amount of undesirable material extracted, and improve the health and safety conditions for machine operators. More selective cutting will reduce costs by allowing the miner to target only desirable materials. In so doing, less waste material will be generated and extracted. Both costs and the surface disturbance caused by mining will be decreased. Operation of mining equipment from a remote location allows miners to withdraw to a safer position further from the cutting operation.

Robotic mining requires development of sensors that can identify different ores and flexible control systems for cutters, both of which can be operated remotely. Prototype machines for potash and coal mining have already been developed and are currently being tested (Fuentes-Cantillana et al. 1992, Chamberlain and Stewart 1992).

Geographic information systems (GIS) utilize a database, plus overlay and mapping capabilities to merge large amounts of spatial information. Biological, geophysical, engineering and sociological data can be combined to facilitate analysis of system interactions. GIS models specifically designed to study the environmental impacts of mining are being developed. Since the temporal capabilities of GIS are fairly limited, simulation models of environmental impacts are being merged with traditional GIS.

These enhanced models will have a variety of field applications. It will be possible to optimize the location of mining activity with respect to various environmental and social factors. Monitored environmental data can be interactively analyzed. Reaction times to emergencies will be reduced. Finally, GIS will facilitate prediction of changes to environmental attributes as a result of energy and minerals activities (Johnston et al. 1993).

Mining can be a very disruptive process. Surface mining creates large open pits; both surface and underground mining produce vast quantities of waste material; and ore beneficiation generate tailings. The goal selective mining research is to develop techniques that minimize surface disturbance and enable miners to remove from the earth only the

desirable attributes of the ore body. Several different approaches are being studied, including in situ leach, water jet, laser mining.

In the United States, the higher grade ore bodies of many metals are being mined out. The shift to lower grade material has been made possible through the development of leach methodologies, wherein a process solution (such as cyanide) is poured over extracted, crushed ore that has been piled on a leach pad. If commodities such as copper, manganese, and cobalt could be extracted from their ore bodies via leach methods and without the use of conventional mining techniques, both expense and surface impacts would be dramatically reduced. Ongoing research on leaching is emphasizing the delivery of solutions to the target zone, containment of the solution with the desired zone (and away from any water table), and mineralogical and textural changes caused by leaching.

Not all ores or deposits are amenable to leaching. In such cases mineralized ore must still be removed from the earth. The purpose of both water jet and laser mining methods is removal of only the desired material. In the former approach, a strong jet of water (with or without abrasives) is used to follow a vein of ore, cutting out only the mineralized portions. Laser mining tools are also used for selective cutting, but use light energy instead of water.

A combination of factors including increased environmental awareness, public pressure and increasing competition for land has generated research on waste disposal in underground mines. Eichmeyer and Wilke (1992) of Germany detailed research on mine waste deposition in worked-out coal faces. They concluded that this waste disposal method benefitted the mining operation by lessening the danger of subsidence and decreasing the environmental impacts of mining through reduction of surface waste storage. The authors cautioned that complete containment of the waste material is necessary to insure the protection of ground water.

Injection of fine particle residues and sludges into underground coal mines has proved beneficial in preventing surface subsidence as a result of mining and, in addition, provides storage for mildly toxic substances (Hamm 1992). The injected substances consisted of ashes from domestic refuse incineration plants, sludges from municipal water purification stations and spent foundry sands. In addition, returning potash mine waste underground has been found to be a practical and cost effective solution for potash waste disposal (Prugger 1992).

A common perception of surface mining is that it causes permanent environmental damage to the mine site and devalues the land for subsequent post-mine use. Some recent evidence suggests that, in fact, the opposite can be true;

mining can enhance the commercial value of a piece of land in some instances. A.M. Bauer (1991a), contends that surface mining often provides a piece of land that is of more interest and value than it was in its original state. He argues that the irregular topography, vertical stone walls, rock out-croppings and water bodies that are created by mining are landscape features that are highly valued by the public (Bauer 1991b) . In areas where most open land is dominated by agriculture, mining may be an opportunity to create parks, golf courses, recreation sites and nature reserves (Proctor 1992). In that context, mining presents favorable rather than unfavorable changes for the land.

Petroleum Production Path

Exploration for oil and gas traditionally begins with a geologist and a geophysicist seeking likely areas to drill with the use of highly sophisticated technology and equipment, ranging from analysis of previous drilled wells, aerial photography, computers, magnetometers and gravimeters. The principal method employed, normally by geophysicists, to select the best site is the seismic survey, also known as "doodlebugging." (Petroleum Extension Service 1981.)

Seismic Exploration

The character and extent of an underground structure can be detected in a seismic survey by measuring the manner in which sound waves bounce off the different rock layers back to recording instruments on the surface. The first seismograph was used in 1841 to measure and record the vibrations of the ground during earthquakes. Early geophysical pioneers set off dynamite and recorded the explosions on their instruments several miles away. One of the first non-dynamite methods was the thumper, a heavy steel slab (6,000 lb.) dropped from as high as 9 feet above the surface, creating shock waves. The most commonly used technique now is the vibroseis, a truck mounted vibrator that generates low-frequency sound waves subsequently picked up and changed into electrical impulses by geophones, commonly called "jugs." In mountain regions, helicopters may be used to reach locations where seismic operations are being conducted, thus minimizing surface disturbance. Onshore seismic activity in the United States has declined significantly since the early 1980's (Table IIEii-1).

Potential oil bearing structures form where porous sedimentary rock is capped by rocks with low permeability that block the escape of hydrocarbon fluids. An estimated 80 to 90 percent of proven oil and gas reserves are found in geological formations known as structural traps. The remaining reserves are found in stratigraphic traps and are commonly located by accident as they are more difficult to predict from reviewing geological formations.

Drilling

Despite careful analyses, the only true way to know if oil is present and in what quantities, is by drilling. The proposed drillsite may require a development, wildcat, or reentry well, based on the geological and engineering ideas involved. A development or infield well is defined as a site within the producing limits of an established oil or gas field. A wildcat or exploratory well is typically considered a risky endeavor and often results in a dry hole. Reentry refers to returning to the site of a previously drilled well and subsequently deepening it.

Before the operating company can begin to drill, lease terms, agreements, and required permits, such as right-of-way access, are prepared and thoroughly reviewed by landmen and legal council. Land surveyors are then commissioned to determine and confirm the exact boundaries for the drill-site location. Preparation of the site is normally conducted by an outside contractor who clears and levels the land to accommodate the rig and associated equipment.

The contractor usually drills a water well or installs pumps and water lines to bring water from a stream, river, or lake to supply the water for the drilling mud. An earthen pit lined with plastic is constructed to dispose of the used or unneeded drilling mud, cuttings from the hole, and other non-toxic waste. The hole is often begun by a small spud rig, which drills an initial 20 to 100 feet. After making the site ready, the drilling rig and equipment are transported, erected, and then connected to the various machines, devices, appliances and parts used during operations. This work is known as rigging the derrick or rigging up.

In the United States, only 2% of all oil wells are drilled by petroleum companies. The remaining 98% are drilled by contract drilling firms that negotiate one of the following contract alternatives with corporate drilling engineers: turn-key: a pre-determined all inclusive amount; footage contract: agreed upon rate per foot drilled; daywork contract: compensation is made, even when drilling is suspended, but any depth may be reached. The number of rotary rigs in

operation in the United States has decreased substantially since the early 1980's, a result consistent with the decrease in seismic activity noted previously (Table IIEii-1).

Once the rig is in position over the hole previously made by the spud rig, drilling is ready to begin. The rotary drill system is lowered into the well with pipes, referred to as the drill string, turning an attached drill bit consisting of revolving cones with teeth that are used to grind and crush the rock as the bit spins. During drilling operations mud is pumped down the pipe to flush out the particles. The mud fluid acts to cool and lubricate the drill bit, maintain pressure in the well, and prevent water seepage from the rock layers. The mud functions as a monitor of the progress of the well, providing important warnings to eliminate dangerous gushers or blow outs. As the well is driven deeper, the whole drill stem and bit are pulled out of the hole in order to change bits, run samples, or cement and case to prevent the walls from collapsing. This process is called tripping out.

To assist the operator assessing the progress of the drilling process, a thorough examination of the formations is generally conducted by a mud logger. The logger, usually a geologist, examines rock cuttings as they come up the hole carried by the drilling mud. The logger records the characteristics of the rock and its hydrocarbon content. The drilling mud is also checked for gas to avoid blowouts and hydrogen sulfide hazards. Devices called logging tools lowered into the well to gather information about the geologic formations penetrated by the hole. Logging companies operate portable truck mounted laboratories with extensive computer capability to measure, analyze, and record parameters including radioactivity, electrical conductivity, porosity, permeability, density and many others. Drill stem tests (DSTs), measure the formation pressure in the hole. Core sampling may be done to extract a small cylinder of the rock formation for detailed examination.

Parallel with the decline in seismic work and rotary drill rig counts, has been a decline in exploratory well drilling (Table IIEii-2). Slightly less than 4000 exploratory oil and gas wells were drilled in 1991, compared to almost 16,000 in 1982. Possible reasons for this precipitous decline are addressed in the oil and gas commodity chapters. Although well numbers have dropped, average depth per well has remained fairly steady, suggesting that firms are not altering the geologic structures they target in response to the change in domestic activity.

After testing and much data collection the decision is made on whether to set production casing and complete the well as a producer or to plug and abandon it. There has been a slight decline in success ratios in recent years. In 1977,

27.1% of exploratory wells were drilled successfully. By 1991, that ratio had declined to 23%. In any case, drilling is much more likely to be successful now than was the case in the 1960's when as many as 84% of new wells were dry.

If an economic reservoir has been reached, it is usually capped with a christmas tree, a collection of control valves, pressure gauges, and chokes at the head of the well tubing. Petroleum may exist in a formation that has low or limited pressure and can not flow to the surface by natural reservoir energy. In such cases, some form of artificial lift is needed to raise the oil to the surface, e.g., a gas lift, hydraulic pumps, submersible pumps, or sucker rod pumps. The latter, called a pumpjack, is very commonly seen on the horizon, employing a simple suction pump action to raise the oil.

However, if a well will not flow naturally or only in small quantities, the reservoir engineer may consider stimulating the well with one or more of the following methods. Explosives, developed in the 1800's, are used to enlarge the wellbore and eliminate formation plugging. Acid treatment is often used in limestones. It is performed by pumping acid into the wellbore, causing existing channels to enlarge or inducing new ones. Hydraulic fracturing cracks within the oil-bearing formation, and then nutshells, glass, or aluminum materials called proppants are pumped down the well to hold the fractures open, creating a more permeable channel for the flow of oil and gas.

Crude oil obtained from each reservoir is unique, ranging from light volatile liquids or gases that condense into liquids, to heavy tar and waxy mixtures that have to be warmed before they can flow. Oil also differs in texture, smell, and color, which can range from green or yellow to brown or black. Crude oil may contain a number of less desirable chemicals in varying quantities, such as sulphur (sour crude) and vanadium, that make it less valuable. The quality of natural gas can also be less attractive in the presence of other gases including nitrogen and carbon dioxide.

Once production begins, the well's natural pressure starts to decline, leaving behind as much as two thirds of the reservoir's oil in the ground. In order to recover as much as possible, secondary and tertiary recovery techniques are employed. Secondary techniques include fluid-injection such as waterflood or a high-pressure gas drive. Tertiary or enhanced oil recovery (EOR) treatments include thermal or chemical methods. Heated water, special chemicals or solvents are introduced to force more oil to the surface. Implementing these costly methods in a particular well or field is generally dictated by petroleum prices. When a well's economic production decreases to production rates of less than 10 bpd it is termed a stripper well.

When a well exhausts its economic petroleum reserves entirely or a large amount of water is present, operators

may abandon it. There are specific requirements and regulations to be adhered to by the operator for abandoning a well and it may be necessary to plug the well.

The cost of drilling and equipping a well depends on many factors. Wells in remote areas require access roads and drill pads are more costly to construct in rugged country. Deeper wells are more expensive to drill than are shallower wells and the harder the material through which the drill must cut, the higher the cost. Compliance with environmental regulations is sometimes costly. In pristine areas, surface disturbance may be unacceptable, necessitating helicopter transport of the rig to the drill site. This can increase costs significantly (in one recent case on the Bridger-Teton NF, a tenfold increase to $4,000,000 for a single test hole). In some areas, wells that produce sour petroleum must be fitted with devices that capture the escaping sulfur dioxide gas. Finally, it should be noted that reclamation is more costly and difficult in some areas than in others.

Oil and Gas Reclamation

A producing oil and gas field consists of individual wells linked by roads and possibly, in addition, an infield collection system. Wells are typically spaced 1 per 40 acres, but may be closer together, such as in fields producing from more than 1 formation. Individual drill pads can be as large as 5 acres, but more commonly fall in the 2-4 acre range (table IIEii-3). The access roads require between 2 and 82 acres per mile depending upon slope conditions.

Oil fields can encompass very large areas. Prudhoe Bay Field on the north slope of Alaska, the largest domestic oil and gas field, has facilities that cover 200 square miles (Office of Technology Assessment, 1988, p. 34). Of course, virtually all other oil fields in this country are smaller than Prudhoe Bay, but fields covering 10 to 50 square miles are not uncommon.

As is the case with mining, reclamation of oil and gas operations will vary depending upon surface ownership and applicable regulations. The Federal government oversees reclamation of oil and gas operations on Federal public lands. For private land, reclamation requirements for oil and gas are established at the state level and are not consistent between states (Dimatteo 1992).

On Federal lands the lease operator must develop a reclamation plan that, once approved, becomes part of the

surface use plan of operations. The reclamation plan will address all types of surface disturbance and typically includes methods for reclaiming mud pits and pipelines, abandoned roads and drill holes (USDI, Bureau of Land Management and USDA, Forest Service 1989). Also, oil and gas operators must post a bond to the appropriate surface land agency. The purpose of the bond is to protect the U.S. government from costs associated with operator failure to meet royalty obligations or perform adequate site reclamation and well plugging. This bond is later released after site operations have been completed and the site has been successfully reclaimed according to the reclamation plan (USDI, Bureau of Land Management and USDA, Forest Service 1989).

Holes drilled for exploration or upon abandonment of an oil well should be plugged, sealed or capped to prevent accidental injury to livestock, people and wildlife and to preclude groundwater contamination. Provided that the hole contained no water or only static water when drilled, a drill hole can be plugged by filling the hole with bentonite pellets and then capping with three feet of cement. For drill holes where artesian water was encountered, the entire hole must be plugged to the surface with cement (USDI, Bureau of Land Management 1992). Alternatively, drill holes that contain water can be converted to a water well or a monitoring well for assessing water quality (USDI, Bureau of Land Management 1992).

Pits used for disposal of drilling fluids and water from the drilling operation must be reclaimed. Hazardous substances in the pits must be removed and the pit allowed to dry prior to filling (USDI, Bureau of Land Management 1992). The pit area should be filled and mounded to allow for settling, topsoiled and revegetated with species appropriate to the post-mine land use (USDI, Bureau of Land Management and USDA, Forest Service 1989). Reclamation of pipelines may involve filling in of cut hillsides, reducing and grading cut and fill slopes to conform to adjacent terrain, replacement of surface soil material and revegetating these areas to prevent erosion and restore the land's productivity (USDI, Bureau of Land Management and USDA, Forest Service 1989).

In addition to plugging the actual drill holes, the well site itself should be reclaimed. Well site reclamation should be planned for both producing and abandoned wells. For producing wells, any part of the site not required for well operation can be reclaimed immediately to prevent erosion and re-establish vegetation. All disturbed slopes should be graded and recontoured to blend with the adjacent terrain and then revegetated with suitable plant species (USDI, Bureau of Land Management 1992).

Technological Advances in Oil and Gas Extraction

The oil industry conducts active research and development (R&D) in all areas - exploration, drilling, and extraction of oil and gas as well as refining, transportation, and marketing. As with mining, most R&D in the relatively mature oil industry leads to incremental advances, rather than major "breakthroughs." Technological advances, including three-dimensional seismic, updated computer modeling, and horizontal drilling, were introduced during the 1980's.

Three-dimensional (3-D) seismic techniques combine the high-capacity computers able to analyze billions of pieces of data and imaging software to improve the ability to represent and analyze potential oil reservoirs underground. By providing a clearer picture of the oil-bearing formations, 3-D seismic can be used to optimally position a well, design effective fracture programs, realize a higher success rate, and gain increased production from fewer wells.

Highly sophisticated computer modeling, developed by both major and independent oil producers, depicts reservoir drive mechanisms, fluid properties, thickness of producing zones, rock porosity and permeability. Other computer programs predict the pressures in the underground rock, determine past temperatures that generated oil, and locate areas to which oil is likely to have migrated.

Horizontal drilling typically begins with vertical drilling. The drill bit is then angled into an oil-bearing formation, parallel to the surface. Production is obtained from formations with non-connected vertical fractures, which are all the same depth from the surface. The first four commercial horizontal wells were drilled in 1985 increasing to 300 in 1989 and 800 in 1990. In developing a field, horizontal drilling can provide lower costs with fewer wells drilled and greater flow per well. On a per well basis, the costs are generally higher than vertical methods, and there is more risk of losing a well. Horizontal drilling, can be viewed as an extreme form of directional drilling.

Directional drilling has been used in a variety of situations. Rivers, hills, or other obstructions may make drilling vertically impossible. Relief wells may be drilled to rescue a blowout or if other problems occur downhole. In the vicinity of salt domes, directional drilling can bypass these areas. Primarily, directional drilling is used to drill multiple wells from a single offshore platform. In addition, directional drilling facilitates access to an increased number of geologic structures from a single drill pad, thus decreasing environmental impact.

ENVIRONMENTAL IMPACTS AND LEGISLATION

The first half of this chapter presents a brief overview of some of the environmental impacts that could potentially occur as a result of various types of energy and mineral activities, as well as factors that impact the magnitude and duration of the environmental impacts. The second part of the chapter contains a discussion of the most important of the Federal environmental laws applicable to energy and minerals activities. The chapter closes with a discussion of the level of environmental regulation faced by the extractive industries.

Environmental Impacts

Visual Impacts

Visual impacts are classified as an environmental impacts because energy and minerals activities have the potential to degrade scenic beauty. The degree to which exploration for or production of nonrenewable resources affects scenic beauty depends upon the commodity and location involved, as well as the stage of development.

Because of the relatively short-term nature of the exploration process for oil, gas, and minerals, visual impacts from seismic, core drilling and other related activities is short lived. As a result, efforts to limit the visual impact of exploration are only rarely undertaken. If exploration is successful, and development and production follow, the duration of visual impacts will usually be much longer, consequently concern about limiting visual impacts grows.

A producing oil field can have a life of more than 30 years, can cover several square miles or more, and could contain hundreds of wells. However, most of the oil field facilities including the pumping wells, collection stations, access roads, and pipelines are spaced at intervals over a large area (e.g., a 40 acre spacing of wells). Production wells are not as tall as the rigs needed to drill the wells, and the mud pits and reserve pits that were created in the exploration and production process are not present during the production phase. In hilly or wooded areas, much of the production equipment may be hidden from view, whereas on grasslands this would not be the case. Nonetheless, it is often possible to block the view of tanks and well heads with indigenous vegetation or to camouflage their appearance by painting to

match the surroundings.

Operating mines typically cover a smaller area than most oil fields, but visual impacts within the area of operation are usually much more intense. This is especially true for open pit mines, which may require the removal of thousands or millions of tons of material, both waste rock and ore. The vast majority of this material will end up in waste and tailings piles. While the workings of underground mines are not visible at the surface, the tailings and waste rock piles from the excavation and mill processing, as well as the millsite operations and access roads, are generally visible. However, because underground mines are typically much smaller than open pit operations, the total magnitude of visual effects from underground mines is usually smaller than is the case for open pits.

Ecosystemic Impacts

Energy and minerals activities have the potential to impact ecosystem health, defined as the degree to which the integrity of the soil and ecological processes are sustained. Ecological processes include nutrient cycling, energy flow, and the ability of the system to recover from natural disturbance.

Reconnaissance exploration processes for energy and mineral extraction have very little impact soils or ecosystem functioning. However, detailed exploration may be accompanied by road building, vegetation removal, the excavation of trenches or pits, and drilling, all of which has the potential to cause soil compaction and changes in soil chemistry. This is particularly true for petroleum industry drilling activities and the associated storage and disposal of drilling fluids and coproduced brines and petroleum. Spills of hydrocarbons, either by blowouts or other forms of leakage or seepage, onto the lands surrounding the drilling and collection infrastructure are also possible. Because of the shallower depth and the lack of use of specialized drilling fluids in mineral exploration drilling there is a smaller chance of producing toxic materials from these types of drill holes.

During the production phase, the natural ecosystem is essentially displaced by the energy or mineral operation. Impacts on surrounding areas vary from minimal to extensive depending upon the type and magnitude of the operation. Changes in local or regional air quality are possible. In addition, mining and petroleum production have the potential to permanently change landscape contours and soil structure. Redirected water flows cause changes in vegetation, as do

altered slopes, aspect, and soil character. These changes in turn lead to new patterns in nutrient cycling and energy flow. Because water is the ecosystem component with the most off-site implications, it discussed in more depth later in this section.

Little is known about the impacts of extractive activities at the landscape scale. The focus of landscape ecology is the distribution and proportions of plant associations, i.e., patches or habitat types (Kotliar and Wiens 1990). Unfortunately the degree to which resource development affects patchiness and alters the connections between patch types is unknown.

Water Quantity

Reconnaissance exploration for energy and minerals has a very small impact on water availability and quality. However, detailed exploration and development activities for energy and minerals can have a significant effect on regional water quantity and quality. Average water demand for oil and gas drilling is about one acre-foot per 3,000 feet of depth drilled (USDI, Bureau of Land Management 1980). Clearly, development drilling of a large field, with many wells extending to depths below 10,000 feet, would require an appreciable amount of water. If water is not available locally it must be trucked to the drilling sites. Similarly, detailed exploration and development drilling for minerals can use significant quantities of water. Mineral exploration drill holes are usually much shallower than oil development wells, although they tend to be spaced much more tightly.

Once production is initiated from an oil and gas field little water is required. In contrast, an operating mine can have very significant water requirements. Water is a vital component for most milling processes during the crushing and grinding stages, and is used in combination with (most) chemical reagents to separate the ore mineral from the waste rock. In addition, the ground waste rock from the milling process is usually transported from the mill to the final disposal site in a water slurry. Heap leach operations use water to dilute the cyanide solutions that are sprayed over heaps of ore-containing rock. The pregnant solution is neutralized or recycled after dissolved metals are removed. As an example, the Castle Mountain heap leach gold mine proposed project is slated to use approximately 725 acre-feet of water annually

[33] Sometimes mineral development holes are drilled as close as 50 feet or less from neighboring holes.

during the ten year mine life (USDI, Bureau of Land Management 1990).

Minerals activities involve removal of vegetation and compaction of soil, which can affect percolation and run off rates. Deep mining has also been linked to dewatering of some aquifers. Moreover, surface and subsurface water draw down anywhere in the country can impact instream flow, springs, marshes, and other critical habitat for many plant and animal species including birds, fish, mammals, vegetation and have a significant impact on the entire ecosystem of the region.

Water availability is an especially notable constraint in arid western regions, where close attention is paid to groundwater recovery and recharge. At Barrick Gold's Betze Post Mine for example, 31 perimeter wells and 7 in-pit wells are pumping 4416L/sec (70,000 gpm). Approximately 6% of the water is used in mining operations, 10% for irrigation and 84% reinjected into the water table on the same hydrographic basis as prior to withdrawal (White and Kral 1994). Many other mining operations in the desert portions of this country have a zero discharge permit for waste waters in the mining and mill-milling process. This means that water is recovered and reused from all of the mining and milling processes, including water recovery from the tailings ponds.

Water Quality

Of all environmental impacts associated with energy and mineral activities, water quality problems tend to have the longest duration and to affect the largest areas (National Research Council 1979; U.S. Environmental Protection Agency 1985). Because of this, the final chemistry of the water discharged by energy and mineral operations, as well as the quantity, is an important consideration. Many of the exploration, development, production, post-production and reclamation stages of energy and mineral extraction introduce chemicals to the water being used, or allow the water to come into contact with surface and subsurface rock formations that contain elements. A primary concern at these energy and mineral operations is decontamination and control of the path that water takes after exposure to these contaminants.

The drilling of an exploration test or development well involves the use of drilling mud to cool the drill bit, to condition the hole and maintain its structural integrity, and to carry the drill cuttings from the bottom of the hole to a surface reserve pit. The most commonly used mud is fresh water and bentonite clay, which poses little environmental risk.

If drilling through salt strata, salt saturated bentonitic mud is used to avoid "washing out" the salt zones and causing loss of the hole. Depending upon local conditions, various other elements or chemicals may be added to the drilling mud.

One environmental concern for groundwater is the prevention of contamination of fresh water aquifers by drilling mud while drilling or by interchange of waters of varying quality between aquifers. This concern is met by isolating the fresh water zones by emplacement of "surface" casing through the groundwater and fresh water zones, and/or by placing plugs of cement across other water bearing zones upon completion of drilling.

Fresh water zones are generally well known and isolation of those zones is prescribed by a casing program prior to commencement of drilling. Other water bearing zones can be readily identified by running electric recording devices through the length of the hole upon completion of drilling. Prior to leaving the site, the lessee must follow direction from either a State of Federal regulatory agency as to the proper plugging of the hole by placing cement across these zones.

As noted above, the exploration drilling stages of energy and mineral operations use appreciable quantities of water that become contaminated with drilling chemicals and natural impurities encountered at depth. Oil and gas operators channel this water to lined mud pits where the water is allowed to evaporate. If fresh water and a bentonite clay were used as drilling mud, there is no environmental risk should the reserve pit leak. If the pit has been dug in permeable soil or bedrock, and if salt water or certain mud additives are used, there is a risk to groundwater from pit leakage. This concern is met by lining pits with plastic to prevent leaking. Drillers are required to remove the contaminants from these pits for disposal in landfills or contained and monitored areas (depending upon the types of contaminants). Coproduced brine waters may be piped into nearby lined pits or trucked to designated disposal sites.

When there is significant volumes of produced formation water, it is disposed of by re-injection into the producing formation or other suitable strata. There is a risk to groundwater from improper re-injection of saltwater. This concern is met by disposing of such waters under the EPA's Groundwater Injection Control Program, or a State's program which meets the minimum requirements of the EPA.

The drilling of an exploration test or development well requires construction of a drilling pad, which can range in size from 1/4 to 5 acres. The size is dependent upon the size of the drilling rig, which in turn depends upon the depth of the hole. There is risk of surface water degradation by erosion from new construction. This concern is met by utilizing standard erosion prevention techniques in construction of the drill pad and access road. Upon completion of the drilling

project, which can take a few days to several months, the site and road are reclaimed, or reclaimed to a minimal amount of area needed for production facilities.

There is a risk to surface waters from the surface discharge of produced formation waters or from accidental oil spills. Any discharge to surface waters must meet the requirements of the EPA under the National Pollutant Discharge Elimination System and may require a permit. All production facilities must have an oil Spill Prevention Control and Containment Plan. Such plans typically require that dikes be built around storage tanks.

Mineral drillers typically encounter less contamination of drilling water than oil and gas operators and therefore may not be required to take special precautions with its disposal. However, water quality at producing and post-production mineral operations is a special concern. Mining and milling processes use a variety of chemicals to separate the desired mineral from the ore. Most of the chemicals involved are organics, which breakdown within a short period of time; however, some may be hazardous and long lasting. Moreover, some of the minerals that are found naturally in ores are toxic, such as cadmium and arsenic. These materials are subsequently transported with the tailings to a disposal pond. Over time the water in the tailings pond evaporates, leaving a dry powdery residue. Unless capped or in some other manner reclaimed, these tailings piles are susceptible to erosion, which can lead to surface and groundwater contamination.

One of the most serious water quality problems associated with mining is acid mine drainage (AMD). It occurs when acidic waters leach metals from host rock. In all cases, sulfide wastes exposed to atmospheric weathering will slowly oxidize, yielding metal oxides,and sulfuric acid. The sulfuric acid creates a low Ph (acidic) environment in which most metal oxides are relatively soluble. This is generally a rather slow process, so oxidation may penetrate consolidated process tailings at a few millimeters to a centimeter per year, waste rock at a somewhat slower rate, and exposed sulfides underground at a very slow rate. Nonetheless, surface area may be great, resulting in significant rate of generation of soluble metals.

If an underground mine accumulates water supplied either by snow melt or rainfall seeping through fractures from the surface, then drainage will normally occur from the opening at the lowest elevation. If there are no exposed

[34] Depending upon geology at the site, soluble metals may also be found in water that accumulates in abandoned open pits.

sulfide minerals underground, the drainage may be potable. Presence of oxidizable sulfides, on the other hand, may allow formation of AMD. Although AMD can involve a host of biogeochemical reactions, the formation process usually begins with pyrite, FeS_2, which oxidizes to form sulfuric acid and ferrous sulfate. The rate of this reaction is greatly enhanced by a natural iron-oxidizing bacterium, *thiobacillus ferroxidans*, which oxidizes ferrous to ferric. the latter is a very strong oxidant capable of oxidizing even more pyrite or other metal sulfides. As these heavy metal oxides and salts form, they become relatively soluble in the acidic environment that has been created.

The dissolved heavy metal content of AMD is strongly influenced by acidity (Ph). In general terms, metals which are present initially in AMD will remain dissolved if the Ph remains below (is more acidic than) a value of about 2.5. As Ph is elevated toward 3.0 (less acidity), ferric iron will begin to precipitate as ferric hydroxide, the characteristic reddish-brown slimy deposit which forms on the bottom of channels conducting AMD. The ferric hydroxide will tend to adsorb or at least occlude other heavy metals (excepting manganese in many cases) which will precipitate as oxides or hydroxides. Usually elevation in Ph is caused by neutralization of acidity, resulting from contact of the AMD with solid rock or soil over which it flows. Limestone is the classic neutralizer of AMD, although it often armors with a layer of precipitated ferric hydroxide. This prevents additional contact of the limestone with the AMD and limits neutralization.

Climate is another important contributing factor in AMD. Extremely arid regions, even those where high sulfide ores are common, have fewer problems with AMD. Conversely, regular rains or snow tend to exacerbate the problem. Overall, AMD is one of the most widespread and difficult problems associated with unreclaimed, abandoned and inactive mines. It adversely affects over 6,500 km of rivers and streams in the United States and 1,500 mines with AMD problems have been identified on NFS lands.

Air Quality

The American Petroleum Institute states that "relatively low levels of air pollutants are released during normal drilling operations." Most of these emissions originate as exhaust from internal combustion engines used to power drilling rigs (American Petroleum Institute 1984). Although pipeline compressor stations and oil pumping rigs also usually use gasoline or diesel engines, the infield collection processes of most oil fields are relatively minor contributors of airborne contaminants.

Production may also require installation of a gas treatment plant, or in some cases hydrogen sulfide rich gas is produced in sub-economic quantities in association with oil and is flared. Under the Clean Air Act, the EPA has established air quality standards. Usually the States implement this act through State Implementation Plans. All producing facilities must meet the Implementation Plan.

Active and inactive energy and mineral mines may have air quality problems associated with windblown dust from roads, dry tailings piles, waste dumps, and other workings. In some cases, such as with uranium or heavy metals mines, the dust may contain toxic substances such as uranium, radon gas, copper, and lead (U.S. Environmental Protection Agency 1985).

Factors Affecting the Magnitude of Environmental Impacts

The environmental impacts of various energy and mineral projects can vary widely depending upon a variety of important factors. One of the most important variables in controlling the environmental effects of energy and mineral operations is the original character of the land. The water surplus that characterizes the East results in much different attributes for soil chemistry and compaction, water quantity and quality, wildlife diversity and density, vegetation types, than would be the case for an otherwise similar site in the West. In many cases the more arid western lands, where much of this nation's energy and mineral production occurs, are more sensitive to environmental impacts than the more humid eastern lands. Riparian and wetland areas, regardless of the region of the United States where they are located, tend to have an elevated sensitivity to environmental impacts.

Specific exploration, drilling, mining, and processing methods can cause differential environmental impacts. These may be exacerbated or minimized as a result of the policies of resource firms. Sensitivity to environmental problems and a willingness to adapt can reduce the negative impacts associated with extraction.

Another factor that has a significant effect on the environmental impacts of energy and mineral projects is the existence and stringency of enforcement of environmental laws and regulations by the various federal, state, and local officials. As will be discussed below, many federal laws exist to safeguard the environmental amenities that may be affected by energy and mineral operations.

In some cases adverse environmental impacts at energy and mineral operations sites may be unavoidable while exploration and production is taking place. Many times in these instances the energy and mineral operators provide mitigating actions after the cessation of activities (e.g., reclamation of affected area) or contribute mitigating actions to other areas to offset environmental degradation in the affected areas. For example, in parts of California's arid southeastern region the desert tortoise is an endangered or threatened species. Some proposed and existing mining operations that would reduce habitat within the existing range of the desert tortoise have provided additional sites or dedicated other areas outside of the mining sites to desert tortoise habitat.

Major Applicable Federal Environmental Legislation

Federal environmental laws have had a major impact on the operations of energy and mineral producers, especially during the last two decades. This section gives an overview of the primary environmental laws enacted by Congress since the National Environmental Policy Act of 1969. Discussion is limited to the laws themselves and not the regulations promulgated by the agencies, or states, charged with the enforcement of the legislation. Table IIFii-1 presents a brief annotated listing of these other important federal environmental laws.

In most cases the role of federal environmental legislation has been enacted as a backstop to state, and sometimes local laws and regulations. Federal laws covering environmental characteristics primarily serve as the **minimum** level of environmental safeguards. That is, the provisions of the federal environmental laws are in effect unless the states or localities have enacted legislation that has more stringent requirements than the federal legislation. Also, in many cases the states have the responsibility of enforcement authority for federal environmental laws. However, federal officials may preempt state activities if they determine that states are not enforcing effectively or rigorously enough.

National Environmental Policy Act of 1969 (NEPA)

One of the first pieces of federal legislation dedicated to environmental concerns was the National Environmental Policy Act (NEPA) that Congress passed in 1969. It created an analytical framework for evaluating the environmental

impacts of any major federal action significantly affecting the quality of the human environment. The intent of NEPA legislation is to consider environmental impacts of projects on public lands and to make public the decisions about these impacts. In practice the NEPA process places much authority in the hands of local agency officials in implementing the act.

Section 102 2C of NEPA requires that whenever energy or minerals activities that would have a **significant impact** take place on public lands (including exploration and road building), an Environmental Impact Statement must be prepared. This is a comprehensive document detailing the nature of the environmental impacts of the project and allowing interested parties to participate in the decision-making process regarding the project. If, on the other hand, it is determined that the energy or mineral project would have no significant impacts to the environment, the project operators can prepare a less comprehensive document called an Environmental Assessment (EA) describing the project .

EIS documents must describe the baseline environment, a discussion and analysis of the project impacts and mitigation procedures, and a presentation of alternatives to the proposed action. Included in the baseline study should be planned closure and post-closure activities, such as expected groundwater effects and long-term impacts to background levels of constituents in the soil and air.

Clean Air Act of 1970 (CAA)

The intent of the Clean Air Act (CAA) and amendments is improvement of air quality overall and the maintenance of air quality where standards have already been met. This legislation also authorizes states to set up their own CAA programs with oversight and enforcement authority retained by the EPA. Two kinds of pollutants are mentioned in the CAA, (1) criteria pollutants which are common contaminants that pose a health and environmental threat at relatively high concentrations, and (2) toxic or hazardous pollutants, or those compounds that "may cause or contribute to, an increase in mortality, or an increase in serious irreversible, or incapacitating reversible illness." The latter category of pollutants poses high risks even at low concentrations.

According to the EPA there are currently six criteria pollutants: ozone, carbon monoxide, lead, nitrogen oxides, sulfur dioxide, and particulates. In principle two different types of National Ambient Air Quality Standards (NAAQS) have been established by the EPA for each of these six criteria pollutants, (a) primary standards that are concerned only with human health risks, and (b) secondary standards that address welfare damages such as impacts to infrastructure, aesthetics, and ecological values. At the present time the primary and secondary standards for each of the criteria pollutants is set at the same value.

The EPA is charged by the CAA legislation with defining air quality standards, but the actual fulfillment of these standards is the responsibility of the individual states. The states must present to EPA for approval an implementation plan that lays out the timing and methods they will use to meet clean air standards. In addition, the states must set emission standards for all new sources or major expansions. Air quality standards are based on the available abatement technology and differ according to whether the pollution sources fall within attainment or non-attainment areas. As might be expected, allowable emissions in non-attainment areas are less than in attainment areas.

EPA has also identified eight hazardous air pollutants under the original CAA legislation. Because of the greater stringency of laws governing the actions of industries that emit hazardous pollutants relative to criteria pollutants and the consequent higher economic costs, EPA has been slow to list other airborne compounds as hazardous or toxic.

Clean Air Act Amendments of 1977 and 1990

These amendments to the original legislation of 1970 were concerned with extending the impacts of and addressing the problems that states and regions had in complying with the original CAA. One of the primary features of the 1977 amendments to help communities reach compliance with the EPA air quality standards is a requirement for new sources or major expansions of existing sources of pollution in non-attainment areas to not only meet the stricter standards for non-attainment areas, but also to offset the additional pollution that they would emit. As an example of one action caused by this requirement, an oil company located in the southern California non-attainment area bought up and removed from service many old cars that exceeded the new car emission requirements and thus was able to complete the refinery expansion in the region. As stated by the EPA, "[p]ermits cannot be granted to these sources unless the state can

demonstrate that emissions resulting from commencing or expanding operations would not jeopardize the region's progress toward attainment (EPA, 1988)."

Another feature of the 1977 amendments is the establishment of the concept called Prevention of Significant Deterioration (PSD) for regions that currently far exceed present air quality standards. This provision creates an affirmative duty on the part of federal land managers to make recommendations to the states to protect Air Quality Related Values (AQRVs) in the PSD process, regarding sensitive regions such as Wilderness Areas, and National Parks and other areas with valuable environmental amenities. It also mandates stricter standards for air quality to ensure that the air quality would continue to remain well above minimum standards.

One provision in the 1977 amendments of special interest to the mining industry is the Non-ferrous Smelter Order (NSO). Since the 1970 enactment of the original CAA the mining industry noted that proven technologies did not exist for smelter compliance for airborne SO_2 emissions and that proposed future standards would cause significant financial hardships for the industry. As a result of these arguments Congress created a limited extension for CAA compliance for smelters fulfilling the following conditions: (1) the smelter must have existed as of August 7, 1977, (2) the extension applies only to SO_2 emissions, and (3) the operators of the smelter had to demonstrate that the control technology for limiting emissions is not economically available. A number of other provisions were included in this section of the law to ensure that the smelters would not use this extension to preclude the smelter's eventual compliance with CAA air quality standards.

The most recent Clean Air Act amendments of 1990 introduced the concept of emissions trading. These allow industries exceeding (which in this context means emitting less pollutants) the air quality standards in one region to sell their "pollution credits" to industries in the same region that have not attained the regional standards. Energy and mineral industry operators can now exceed air quality standards, even in non-attainment areas, provided that they buy pollution credits from firms in the same region that exceed those standards. This requirement gives firms more flexibility (and sometimes lower-cost options) in complying with air quality standards. Another portion of the most recent Clean Air Act amendments is new control over acid rain. One of the primary precursors of acid rain is SO_2 emissions, and coal-fired electric power plants are the major source this airborne contaminant. As a result, the new controls on the allowable SO_2

emissions from power plants may give an economic advantage to the lower sulfur-content coals found throughout the West over the higher sulfur-content coals found in the East (primarily in the Appalachian region).

Another significant addition in the 1990 Amendments was the requirement that most federal activities, or activities occurring on federal lands, conform with approved and promulgated State Implementation Plans (SIPs). The federal land manager was delegated the responsibility to make conformity determinations, with the consultation of the Environmental Protection Agency. This has the potential to impact mineral operators who must subject their Plans of Operation to the federal land manager to make such a conformity determination.

Clean Water Act of 1972 (CWA)

This legislation mandates the EPA to regulate the discharge of added pollutants into United States surface waters--lakes, rivers, estuaries, oceans, wetlands, and underground waters hydrologically connected to surface waters--using the National Pollutant Discharge Elimination System (NPDES). This legislation also authorizes states to set up their own NPDES programs with oversight and enforcement authority retained by EPA. In addition, the CWA establishes significant provisions for natural resource trustees (states, tribes and federal land managers) to seek damages from polluters in order to restore injured natural resources.

Any entity that adds pollutants from external sources, and then discharges these pollutants into surface waters must get a permit and have the discharges comply with the effluent limits for each contaminant and industry set by the EPA. The effluent limits set under the original act were based on available technology and specified that by 1977 all firms that discharged pollutants use the best practicable control technology currently available (BPT), but that by 1983 they should use the best available technology economically achievable (BAT). The latter standard (BAT) is more stringent than the former (BPT) because the latter standard implies a greater emphasis on more effective pollutant removal and a lesser emphasis on the costs of achieving this higher standard.

Clean Water Act Amendments of 1977 and 1987

As was the case with the CAA, Congress found that industries did not, or could not, comply with the water quality standards under the timetable set in the original legislation. Congress's response to the non-attainment of the water quality standards under the original schedule was to subdivide the classes of pollutants into conventional, non-conventional, and toxic contaminants. Subsequent amendments tended to focus on controlling the pollutants with the greatest health hazards and also to apply cost-effectiveness tests to water pollution control technologies to lessen the economic burden on corporate compliance. Another important provision in the Water Quality Act of 1987 was the recognition of the significance of non-point sources of pollution such as agriculture, silviculture, and active, inactive, and abandoned energy and mining sites. Federal standards were not established for these non-point sources of pollution but grants were provided to states to support their own regulatory programs.

In addition to the effluent standards set by the EPA, each state has the responsibility to define water quality standards for various uses (e.g., fishing, drinking, swimming). Every three years these standards are reviewed, but unlike the CAA, there is no formal relationship between the EPA-set effluent standards and the state-set water quality standards, nor are such standards, by themselves, enforceable through federal citizen suits.

Section 404 of the Clean Water Act requires the Corps of Engineers to regulate dredge and fill activities in navigable waters and adjacent areas. Subsequent interpretation of this section has extended the Corps of Engineers jurisdiction to almost all surface waters of the United States, including wetlands.

Resource Conservation and Recovery Act of 1976 (RCRA – also called the Solid Waste Disposal Act)

This legislation regulates hazardous wastes, controls handling of solid and medical wastes, and regulates Underground Storage Tanks (USTs). This legislation also authorizes states to set up their own RCRA programs with oversight and enforcement authority retained by EPA. Using what is known as a "cradle-to-grave" approach, RCRA tracks solid hazardous wastes from their creation to their ultimate disposal, including all intervening stages such as

transportation, treatment, and storage. The regulation of these substances is conducted under what is known as Subtitle C (or Subchapter III) which covers approximately 500 substances considered hazardous based on criteria such as corrosivity, reactivity, and toxicity. All facilities that handle these hazardous wastes must be permitted by the EPA and include a manifest system that constantly tracks the wastes. Non-hazardous solid wastes are covered in this legislation under Subtitle D (or Subchapter IV). This category of wastes was not regulated under the RCRA legislation of 1976, but provided some funding and technical guidance for individual states to set up programs to regulate non-hazardous wastes.

The original RCRA legislation excluded mining wastes from federal regulation under Subtitle C and the Bevill amendment of 1980 extended this exclusion. Mining-related substances excluded from federal regulation under these laws included solid waste from the extraction, beneficiation, and processing of ores and minerals. However, the hazardous wastes that are included under Subtitle C of RCRA and that are not "unique" to the mining industry are regulated under the 1976 law. The intent of the original and Bevill amendment exclusions for mining-related waste is that they should be studied further before regulations were promulgated. In 1986 EPA concluded that some mining wastes should be regulated under Subtitle D--Non-Hazardous Wastes because of the huge amount of wastes generated, the generally low level of risk associated with them, and the remote environments where they are usually disposed.

Strawman I and II were two controversial discussion drafts released by the EPA that contain proposals for the regulation of mining-related waste under Subtitle D of RCRA. These drafts were only interim discussion papers that contain proposed regulations and were released to foster comments from interested and affected parties. To date, no regulations have been adopted by the EPA to regulate mining waste under Subtitle D of RCRA.

Comprehensive Environmental Response, Compensation and Liability Act of 1980 and amendments of 1986 (CERCLA)

In contrast to the regulation of active "hazardous wastes" covered under RCRA, the intent of CERCLA is to concentrate on compensation for, and federal authority to, clean up "hazardous substance" sites. Note that the courts have found that mining wastes may be hazardous substances even if they are not hazardous wastes, regardless of whether at active, inactive, or abandoned sites. Under this comprehensive legislation (sometimes erroneously referred to as Superfund) hazardous substance disposal sites that may be a risk to human health and safety, or the environment must be

identified. Unlike the federal environmental legislation discussed previously in this section that authorizes the delegation of direct regulatory authority to qualified states, CERCLA has no delegation authorities. Instead, it requires the EPA to actively take part in selecting sites for the National Priority List (NPL – the so-called Superfund list), and when EPA decides to clean up an NPL site, to choose appropriate cleanup technology and remedies, and to attempt cost recovery for its clean-up efforts. Although EPA has no authority to make binding liability determinations, EPA does attempt to determine who will pay for the clean-up and carry out the remedial actions.

Other federal agencies, for non-emergency incidents involving past or present hazardous substance disposal on lands under their jurisdiction, custody, and control, have essentially the same authorities delegated to them by the President as EPA, with the exception that they cannot directly issue clean up orders to polluters. The Forest Service has one of the largest pro-active mine site and landfill clean up programs in the country under its delegated CERCLA authorities. In addition, CERCLA establishes significant provisions for natural resource trustees (states, tribes and federal land managers) to seek damages from polluters in order to restore injured natural resources.

Entities that operated, manufactured, stored, transported, used, or disposed of hazardous substances at CERCLA sites, that now own, or owned the Site at the time of disposal, all hold potential strict (i.e., no fault), joint and several liability to reimburse EPA and/or other federal agencies for their costs in cleaning up hazardous substances. One of the most powerful features of this legislation is the retroactive provisions that assigns liability for cleanup to firms linked to the waste in the past even if they were in full compliance with existing waste standards when they used the substances. A large number of the Superfund sites identified to date are chemical waste sites. Although there are some Superfund sites that are mine sites, most CERCLA clean-ups of mine sites are not, nor are they required to be, Superfund sites. Many of these Superfund sites have been linked with currently operating energy and mineral firms or their corporate ancestors.

Subsequent amendments to CERCLA and RCRA in 1986 and 1992 enacted measures to encourage state participation in the CERCLA process, promote greater federal agency compliance, ensure greater public involvement, promote community awareness of about the risks from Superfund sites, prepare emergency response plans, and facilitate military base closure property transfers. These amendments also require routine reports about the status of Superfund sites from involved entities.

Surface Mining Control and Reclamation Act of 1977 (SMCRA)

This legislation was enacted specifically to regulate the environmental impacts of surface mining coal. Primary concerns of this act are the protection of the aesthetic values, wildlife and fish habitat, mitigation or elimination of water pollution, and reduction of property damage and hazards to life and property from unreclaimed coal strip mines. Requirements of this legislation are the approval of an operation and reclamation plan that includes the "restoration of the approximate original contour prior to the mining operation", and the establishment of an Abandoned Mine Reclamation Fund financed by a tax on coal production. As implied by the name, the Abandoned Mine Reclamation Fund is a pool of funds that states can draw from, after meeting certain statuatory critieria, to fund reclamation activities on the large number of unreclaimed and abandoned mines, both coal and non-coal. The Energy Policy Act of 1992 extends the requirement for payment of these funds through 2004.

Another requirement in SMCRA is the preparation of a study investigating the eventual application of a similar kind of regulatory program for non-coal minerals. Currently there is no federal legislation of this type dealing specifically with reclamation of non-coal mines.

Endangered Species Act of 1973 (ESA)

The intent of this legislation is to conserve threatened and endangered plant and animal species through identification of these species, preservation of critical habitat and implementation of species recovery plans. Section 7 of the Endangered Species Act provides the most powerful tools for protection of listed species and their habitat, mandating that all Federal agencies must determine how to use their authority to both further the purposes of the ESA, and to address existing and potential future conservation issues. This section also states that Federal agencies must consult with the Secretary of Interior to insure that any action authorized, funded, or carried out by a given agency is not likely to

[35]Section Vii of this report discusses funding for abandoned mine clean up in more detail.

jeopardize the continued existence of a listed species, or to result in the destruction or adverse alteration of designated critical habitat. Section 7 consultation is a cooperative effort involving affected parties engaged in analyzing potential effects of proposed actions on listed species and/or critical habitat. Each agency must use the best scientific and commercial data available to fulfill these requirements, and additional federal regulations direct the consultation processes outlined in the ESA.

As with most of the other Federal environmental legislation, the states have the option of enacting more (but not less) stringent laws and regulations regarding the taking of endangered or threatened species. Probably the most relevant portion of this law to energy and mineral operators is the requirement that limits the activities performed on critical habitat of threatened and endangered species. In some cases the effect of this habitat protection provision to energy and mineral operations has been to prohibit or restrict expanded exploration or production activities.

Regulation and Compliance

Energy and mining projects on public and private land are subject to many Federal, state, and local environmental laws. States and localities also have promulgated laws and regulations that can have an important impact on the environmental values at these projects. In general, state and local governments develop regulations for industries active in their region and the stringency of these regulations varies from state to state, and activity to activity. State and local permits cover items such as air and water quality, fish and wildlife protection, site reclamation and zoning. For example, the City and Borough of Juneau, Alaska is typical of many communities in having implemented a mining permitting process that requires conditional use permits for exploration and production (City and Borough of Juneau, 1989). In addition to the zoning approval needed for operating new mines, the large mine permitting process necessitates the operator(s) to fully describe the proposed operations including the methods used for controlling, treating, transporting, and disposing of hazardous substances, sewage, and solid waste. Posting of bonds and reclamation requirements are also mandated by this local government legislation.

The states of Montana and Wyoming have laws which authorize a state board or council to issue siting permits that govern the environmental and socioeconomic conditions of the energy and mineral activity (Montana: Hard-Rock

Mining Impact Act of 1981, Wyoming: Industrial Siting Council and Office of Industrial Siting Administration Act of 1975). Wyoming's Industrial Siting Council and Office of Industrial Siting Administration have been in existence since 1975 and allow for a comprehensive review of the environmental, as well as social and economic impacts, of large-scale energy activities in the state. Under this legislation any industrial activity with an estimated cost exceeding $100 million must submit a detailed description of the proposed project, which is then reviewed by the council and local governments, school districts, public interest groups and individuals for 90 days and discussed in public hearings.

As previously noted, NEPA requires that an Environmental Assessment, or Environmental Impact Statement, be written for any proposed development on public land that has the potential to cause a significant impact. These documents are subject to public comment and the review process can be lengthy, particularly for large complex projects or those proposed for sensitive areas. In addition, any resource operation, regardless of location is subject to regulation under CWA, CAA, RCRA, SMCRA, and ESA. Numerous environmental, construction, and operating permits must be obtained prior to development of a new mine or well to comply with these and other laws. Moreover, operating plans may require federal, state, and local approval with each level of government placing specific requirements on the project design and operating parameters. Coordination between agencies and levels of government can be logistically challenging.

The full extent of the regulations promulgated by the Federal, state, and local agencies enforcing the laws listed in this section are too numerous and complex to present here. Similarly, it is not possible to quantify the cost of compliance in this report. As an alternative, examples of the permits, approvals, and notifications required prior to drilling an exploratory oil well and/or developing a surface gold mine are presented to illustrate the current level of environmental regulation.

Table IIFiii-1 lists the permitting actions required of Exxon prior to drilling an exploratory well on the Custer National Forest. Approvals, permits, and or notifications were needed from 5 federal agencies and 4 state agencies. Had oil and gas been discovered, additional environmental review would have taken place prior to approval of production. Table IIFii-2 lists the permitting actions required of Viceroy Gold during the development of their Castle Mountain Gold Mine. The process of acquiring the permits, approvals and notifications took 6 years. Viceroy invested almost $25 million in exploration drilling, feasibility and engineering investigations and environmental studies prior to mine

NON-FUEL RESOURCES

Methodology

The U.S. Bureau of Mines prepared this analysis of and outlook for nonfuel minerals as a supporting document for the USDA Forest Service 1993 Resource Planning Act (RPA) Assessment. This report discusses mineral supply, including mining, processing, recycling, stockpiles, inventories, production, and imports. The base year for this assessment is 1987. The analysis of mineral availability and the forecasts of U.S. mineral demand are based on basic assumptions developed by the U.S. Forest Service on population, gross national product, disposable personal income, institutional and technological change, capital availability, interest rates, energy costs, and other variables (USDA, Forest Service 1989).

The following commodity sections are intended to provide mineral specific information pertaining to domestic consumption trends and forecasts, and stock levels as well as global availability analyses and production patterns. Special issues are also discussed which may impact on domestic supply, forest lands utilization, and the environment. The historical data base for each section covers a period of approximately 30 years through 1990. For purposes of the discussions on U.S. consumption, the historical data is, in general, presented in terms of apparent consumption. This is defined as the sum of the materials derived from domestic mine production and secondary sources, plus imports minus exports, plus changes in government and industry stocks. The total domestic supply may include domestic production, secondary materials processing, and sales from the U.S. Government's National Defense Stockpile. Departures from the use of apparent consumption are made to gold and molybdenum. For gold, the discussions on consumption are based upon reported consumption in industry and art. For molybdenum, consumption refers to the total reported quantity consumed in all end-use sectors.

In the consumption forecast discussions, the forecast methodology follows the general framework described in

the 1985 Edition of Mineral Facts and Problems. The methodology consists of two components: (1) Statistical analysis and (2) Contingency analysis. The statistical analysis provides a statistical foundation for projecting U.S. mineral consumption. Obviously, for the 50 years into the future called for in the RPA study, there are a lot of factors affecting future demand that are not reflected in the statistical analysis. Therefore, contingency analyses are used by commodity specialists to try to take into account the outlook for these factors of uncertainty. Contingency analysis, by evaluating the influence of the many factors, is necessarily judgmental and varies considerably from commodity to commodity. The methodology used by commodity specialists in judging future demand will also vary. The results of the contingency analyses (forecasts) are illustrated graphically in the individual commodity sections.

Availability analyses are performed using a discounted cash flow rate of return (DCFROR) of 0% DCFROR, with one exception, the availability curve for molybdenum represents a DCFROR of 15%. Availability analyses include total costs for each of the facilities producing this commodity. For different commodities, the year of the analysis varies. The concept of availability is further defined in a separate chapter pertaining to the Technical Discussion of Mineral Supply. Availability, as discussed in the individual commodity sections, is limited to resources in Market-Economy countries. Resource data from the former Centrally-Planned-Economy countries, including the former Soviet Union, were excluded because the data were difficult to obtain, were unreliable, and were not subject to the same cost criteria as were those from operations in Market-Economy countries.

Global trends in mine production for each commodity are illustrated to include the five major producing countries. For most commodities, trends are reported in units of contained metal recovered annually in the country's mining and milling operations. Exceptions are made in a few of the sections. For chromium, it is shown in terms of gross production of both ore and ferrochromium rather than contained metal. In the case of phosphate rock, the trends are representative of the production of the marketable beneficiated concentrate. For construction sand and gravel, and crushed stone, only U.S. production statistics are pertinent to the discussion.

A discussion of the levels of U.S. Government and industry stocks and the factors affecting these levels is presented for all commodities other than phosphate rock, construction sand and gravel and crushed stone. The Government does not hold any of these three commodities in reserve. In addition, industry stock data on the latter two

[36]Mineral Facts and Problems, 1985 Edition, U.S. Bureau of Mines Bulletin 675, pages 6-7.

commodities are unavailable. Information on Government stocks is specific for that which is retained in the National Defense Stockpile, with one exception. Information on gold is for that which is held by the U.S. Department of the Treasury.

Prices

Historic prices for the non-fuel commodites addressed in this section of the report are shown in tables IIIAii-1 and -2, in nominal and real ($1982) dollars. No price forecasts for these commodities are available.

Metals and Nonmetallic Minerals

Chromium

Chromium (Cr) is primarily used in the metallurgical industry, and most of that is used to produce stainless steel. The remaining domestic use of chromium is in the chemical industry and the refractory industry. Chromium chemicals include pigments, plating solutions, and wood preservatives. Chrome-mag bricks are used in high temperature applications such as steel making furnaces, cement kilns, and heat exchangers associated with glass producing furnaces.

There is no substitute for chromium in stainless steel nor for chromium in superalloys. Superalloys are the major strategic end use for chromium. Stainless steel is an advanced material relative to common grades of carbon steel and alloy steel. And stainless steel is more cost effective than carbon or alloy steel in many applications when considered on a life-cycle cost basis.

Demand--Chromium consumption, both as an alloying element and as a refractory, was propelled by the development of the steel industry in the 20th century. U.S. stainless steel production has reached about 2 million tons annually (about 2% of U.S. steel production overall) and world stainless production has reached about 9 million tons annually (about 1% of world steel production overall). Chromite demand for refractory use has declined as steel

production has shifted from the open hearth to the electric furnace process. Demand for chromium in chemicals has also declined over the past two decades.

Figure IIIAiiia-1 depicts the recent trend in total domestic chromium apparent consumption. Because the U.S. does not mine chromium ore (commonly called chromite) domestically, consumption has been met through imports of chromium materials, increasingly imports of ferrochromium (FeCr).

U.S. chromium demand is expected to continue to be dependent on the growth of stainless steel production. Domestic refractory demand is expected to continue declining until about 1992 when the last open hearth furnaces are expected to go out of production. Chemical demand appears steady.

If domestic stainless steel production grows at 3% annually during the period 1989-2040, U.S. consumption would grow at an average annual rate of 3.37%, starting from 1989. Figure IIIAiiia-2 shows U.S. chromium consumption forecasts under this assumed 3% stainless steel growth scenario.

Geology--Chromite is the only mineral mined for chromium. Chromite ore is mined as a primary product. Chromite ore is not a byproduct nor a coproduct of the mining of any other mineral. Typical chromite ores contain about 30% chromium. The other major constituents of chromite ore are iron and oxygen. Aluminum appears in some ores.

In situ chromite ore resources split into two categories based on Cr_2O_3 content; a high-grade group ranging from 34% to 43% Cr_2O_3 and a low-grade group ranging from 9% to 26% Cr_2O_3. The weighted average Cr_2O_3 content of the high-grade group is about 39%; the low-grade group, 16%. In situ chromite ore is mined and beneficiated to produce commercial chromite ore.

Chromite ores are categorized by marketability and uses, chromite mineral distribution, and deposit type. Marketability and usage are effected by relative amounts of aluminum and iron. High aluminum contents are desired for refractory use while the chromium-to-iron ratio of an ore will have a direct relation to the final Cr content of a chromium ferroalloy made by smelting that ore.

Based on chromite mineral grain distributions, deposits or occurrences can be grouped into four categories: massive (nearly all chromite), disseminated, schlieren (chromite as streaks), and spotted. In general, the Cr_2O_3 grade

range of in situ chromite ore in massive deposits will approximate those of the chromite spinel itself, while those of other mineral distributions are all less than 35%.

Deposit types include unweathered and weathered. In-place, unweathered deposits are categorized by structure as either podiform (large in all three dimensions) or stratiform (large in two dimensions). Stratiform classification is generally limited to chromite deposits of less than 5 meters in thickness, examples of which are the Bushveld Complex in South Africa, the Great Dyke in Zimbabwe, and the Stillwater Complex in Montana. Weathered deposits include eluvial, alluvial, and lateritic chromite deposits, all of which are relatively low (less than 10%) in Cr_2O_3 contents.

Mining and Processing Technology--Chromite deposits are mined by both surface and underground techniques. Mining methods include labor intensive, partially mechanized, and mechanized operations depending on local economic conditions. Beneficiation is typically carried out at the mine site. Beneficiation methods are tailored to ore characteristics and end use requirements. Methods in use include hand sorting, screening, gravity separation with tables, spirals, or jigs, and heavy media separation. Mining operations vary greatly in size, with typical production rates ranging from 20,000 to 500,000 mt per year.

Market Economy Countries' chromite mining operations can be split into four basic categories, highly- and semi-mechanized surface mines and highly- and semi-mechanized underground mines. High mechanization (drills, loaders, and trucks) is represented by the surface mining operations in Finland, Madagascar, South Africa, and Brazil. Semi-mechanized surface mining (some machines utilized) is mostly done at small operations in India and the Philippines. Highly-mechanized underground methods (sub-level stoping, sublevel caving, cut and fill, shrinkage stoping, vertical crater retreat, and breast stoping) are used in mining large podiform deposits and thicker (greater than 1.5 m) stratiform deposits. Examples are certain operations in Zimbabwe, the Philippines, Greece, New Caledonia, Turkey, India, and South Africa. Semi-mechanized underground mining methods (cut-and-fill, breast stoping, and resue mining) are used in mining small podiform deposits and thin (less than 1.5 m) stratiform deposits. Examples are most of the operations in Zimbabwe, Turkey, and South Africa.

To produce chromium for use in metallurgical applications chromite ore is mined, then smelted with other materials in an electric furnace to produce FeCr, a chromium-iron master alloy used to introduce chromium to stainless

and alloy steels.

For chemical industry applications chromite ore is mined, then kiln roasted with soda ash. The product is leached to produce a sodium chromate-containing solution that is treated with sulfuric acid to produce sodium bichromate from which other chromium chemicals are produced.

For refractory industry use, chromite ore is mined, crushed and sized, then formed into bricks by bonding controlled quantities and sizes of chromite and magnesite.

Resources--Table IIIAiiia-1 lists world chromite ore reserves and reserve base. According to the gross tonnages shown, the Republic of South Africa and Zimbabwe account for 95% of the world's reserve base of chromite ore.

Availability analysis for chromium estimated 202.5 Mmt of chromium in 10 market economy countries. Table IIIAiiia-2 lists the potential availability of metallurgical chromite ore from current and potential major market economy producers. Metallurgical chromite accounts for about half of recoverable chromium, other types being chemical, refractory, and foundry sand. Most of the 145 Mmt available chromite is located in South Africa, with India and Zimbabwe as other significant sources. South Africa is, over all, the lowest cost producer of chromite ore. There are also important chromium resources in the former U.S.S.R. and Albania, but lack of resource and cost data for those countries preclude their inclusion. Chromite resources in the United States are not considered of economic quality to be considered reserves and are not included in this availability analysis.

Figure IIIAiiia-3 shows the availability curve for metallurgical chromite from producing and non-producing operations that would have chromite ore as its major source of revenue. The 145 Mmt represented on Table IIIAiiia-2 contains reserves which range in costs from a low of $53/mt to a high of $243/mt, averaging $101/mt. Of the 145 Mmt of chromite ore available meeting that criteria, about 100 Mmt is available at costs under $100/mt.

Table IIIAiiia-3 lists the potential availability of high carbon (HC) FeCr from all major market economy producers and potential producers, except Japan and Sweden which, since they had no domestic chromium resources, were not included in the availability study. Most of the 74 Mmt available HC FeCr is located in South Africa, with Zimbabwe, Finland, the United States, India and Brazil as other significant sources. Turkey, followed closely by South

Africa, is the lowest cost producer. The United States ranks as the third lowest cost producer of HC FeCr.

Figure IIIAiiia-4 shows the availability curve for HC FeCr. The bulk of the 74 Mmt of HC FeCr is available at prices well under $.50/lb FeCr.

World Production--Chromite ore is principally mined by the former U.S.S.R., South Africa, India, Finland, Albania, Turkey and Zimbabwe, and is or has been mined over the last 30 years by 22 other countries. Figure IIIAiiia-5 shows world chromite ore production over that period. The former U.S.S.R. and South Africa dominate production, consistently producing about two thirds of production. Production has been strong since 1984. It peaked in 1988 at 12 Mmt, three times the production level in 1960.

The major producers of FeCr are South Africa, the former U.S.S.R., and Japan. Zimbabwe, the People's Republic of China, Finland, India, Brazil and Sweden also produce significant quantities. The United States was a principal producer of FeCr until 1981 when economic conditions forced a downturn in production. The four current major producers contribute about two thirds of supply with 21 other countries variously supplying the remainder. Figure IIIAiiia-6 shows the breakdown of production since 1974. Recent production is the highest ever, reaching almost 3.5 Mmt, gross weight.

World FeCr production capacity increased about 300 kmt, measured in contained weight, in 1989, and by a similar amount in 1990 resulting in a world FeCr production capacity of about 3 Mmt. Despite strong demand for FeCr for production of stainless steel, excess FeCr production led to a decline in FeCr prices from their peak values in 1988. As a result of declining prices, there has been a delay in the start-up of new furnaces, the idling of some existing furnaces, and the closure of one plant.

World chromite ore and FeCr production is expected to respond to increasing demand. The relative distribution of chromite ore and FeCr production among world producers is expected to remain as in Figures IIIAiiia-5 and IIIAiiia-6. South Africa and former U.S.S.R. will continue to dominate chromite ore, followed by a few other producers at a second level far below the major producers. South Africa and the former U.S.S.R. each account for about 30% of world chromite ore production. The next largest producers, including Albania, Finland, India, Turkey, and Zimbabwe, account for about 5 to 7% each.

National Defense Stockpile--The NDS contains chromium material in the form of chromite ore, chromium ferroalloys, and chromium metal in excess of 1 Mmt, contained chromium. Figure IIIAiiia-7 shows that government stocks were halved from 1970 to 1980.

Chromite ore remaining in the stockpile is being converted to FeCr because domestic FeCr production capacity is not adequate to meet anticipated domestic demand under mobilization conditions, and chromite ore must be converted to FeCr before it can be used to make stainless steel. The conversion process started in 1984 and is expected to continue through 1993.

Security of Supply--While resources of chromium are abundant, security of supply is an issue. Production is limited to a few producers, and the major producers are politically or economically changing or are geographically distant from the United States. These factors make an adequate, dependable, and secure source of supply of chromium products questionable.

South Africa has supplied about half of market economy country demand. The former U.S.S.R. has been the major planned economy country supplier. Trade barriers in the form of punitive tariff rates have been imposed on former U.S.S.R. chromium materials. In 1986 the United States limited trade with South Africa through the Comprehensive Anti-Apartheid Act. Under the Comprehensive Anti-Apartheid Act, chromium, including chromite ore and FeCr, was found to have been a strategic mineral essential for the economy or defense of the United States that was unavailable in adequate quantities from reliable and secure suppliers. This finding permited chromium imports from South Africa which would otherwise have been prohibited by the Comprehensive Anti-Apartheid Act.

South Africa and the former U.S.S.R. are currently undergoing significant internal political changes. The results of these changes are expected to improve the political stability and productivity of those countries in the long term. In the short term, chromium supply disruption in those countries could result from internal political causes, perhaps even in both countries at the same time. Should supply from one of the two major producers be completely interrupted for an extended period, the remaining producers could not compensate for that loss in the short term. Comprehensive Anti-Apartheid Act sanctions were terminated in 1991.

Environmental Concerns--Hexavalent chromium compounds (i.e. compounds in which chromium is in the +6 valence state) are generally recognized as being hazardous. Some of these compounds (e.g., some chromates) are carcinogenic and water soluble. These compounds are formed by the oxidation of trivalent chromium at extremely high temperatures. Current processing technologies do not operate at such temperatures. Chromium compounds such as oxides, as found in chromite ore, and those found in stainless steel, are not hazardous.

Special Issues Related to Forest Lands--Chromium resources in the United States are located primarily in Alaska, California, Maryland, Montana, Oregon, and Pennsylvania. The U.S. Geological Survey identifies the Appalachian Mountains as having a high potential for chromite resource discovery.

The Forest Service was involved in administrative litigation over chromite occurrences in the Absorakee Bear Tooth Wilderness in the Custer and Gallatin National Forests in Montana.

Private sector plans to develop chromium resources in Stillwater Complex, Montana, include a mine and a smelter. Should these plans be executed, Forest Service lands would be affected.

Copper

Because of its high electrical and thermal conductivity properties, durability, strength, and high resistance to fatigue and creep, copper (Cu) has diverse uses in most industrial sectors, including the transportation, telecommunications, construction, and defense industries. Copper and copper alloy wire are used in the manufacture of electric motors and generators, power transmission lines, housing and industrial wiring and all other types of electrical wiring. Copper is used in busbars, electrical and electronic tube components, switches, contacts, printed circuit foils, circuit breakers, transistor bases, rectifiers and in many specialized electronic uses. Copper also is used for plumbing, telecommunications, industrial equipment exposed to nonoxidizing acidic solutions, corrosion resistant equipment, marine biofouling applications, desalinization plants and many nonelectrical industrial machinery and parts. Copper is used for ordnance, where, as brass, it is used in shell cartridges, fuses and other ammunition equipment. Copper chemicals are

used widely in agriculture, medicine and as wood preservatives. Miscellaneous uses of copper include chemicals and inorganic pigments. Copper coinage was replaced in large part by zinc in 1982 when the traditional copper penny was replaced with a new zinc-copper penny consisting of only 2.4% copper.

Demand--Trends in copper consumption for the United States and production are shown in Figure IIIAiiib-1. U.S. consumption of copper ranged from 1.5 Mmt to 2.4 Mmt from 1960-1990, suffering major setbacks during periods of economic slowdown. Peak consumption of 2.4 Mmt occurred in 1979, but declined in the 1982 recession to 1.8 Mmt. Since then consumption levels have remained relatively constant at approximately 2.2 Mmt since 1984. Annual domestic production of refined copper began to fall short of consumption demand starting in 1966. Since then, with the exception of low demand years, a portion of domestic consumption has been met by imports. From 1984 to 1987 imports met about a quarter of demand. However production rebounded in the late 1980's, to matching peak production levels of the 1970's. Domestic production met 97% of copper demand in 1990.

The use of copper is often associated with the higher standard of living that results from electrical and electronic applications. Although copper consumption has been reduced in some traditional end-uses owing to substitution, downsizing and changes in technology, overall copper consumption for all electrical uses has expanded significantly, both in total amount as well as in percent market share. In the United States, as shown in Table IIIAiiib-1, copper in all electrical uses has expanded market share from 52% in 1960 to over 70% in 1990. There is currently no suitable substitute for copper in the proliferation of electrical applications. The U.S. population currently consumes about 20 lbs. of copper per person per year. World per capita copper consumption is 4.7 lbs., indicating considerable potential for growth in the consumption of copper.

U.S. copper consumption grew at an average annual rate of 1.34% from 1950 through 1988. If this trend were to continue, U.S. copper consumption in 2040 would be 4.4 Mmt. Figure IIIAiiib-2 shows actual apparent consumption for 1960 through 1990 and U.S. copper forecasts through 2040.

Geology--According to their mode of origin, copper deposits may be grouped in the following broad genetic

[37] Calculated from data appearing in the U.S.B.M. 1990 Annual Report, Copper Chapter.

classes: (1) porphyry copper deposits and their associated skarn, hydrothermal veins and replacement breccia deposits, (2) sedimentary and metasedimentary deposits, (3) volcanogenic and metavolcanogenic deposits, (4) deposits associated with ultramafic, mafic and alkaline ultrabasic and carbonatite rocks and, (5) veins and replacement bodies associated with metamorphic sequences, not otherwise classified. Though the massive sulfide, and vein and replacement deposits associated with the last three classes are much more numerous than the porphyry and stratiform sedimentary deposits, they tend to be smaller in both capacity and reserves. Generally, the massive sulphide and vein deposits contain a wider variety of other mineral co-products. However, the porphyry deposits tend to be larger, comprising the larger share of world copper output. In the United States, porphyry copper deposits comprise about 93% of established mine capacity.

Mining and Processing Technology--Copper ores are mined by underground, open pit and/or leaching methods. Most of the ores processed are copper sulfides or mixed base-metal sulfides that require crushing, fine grinding, and flotation in cells with reagents to separate them from the host rock, thereby concentrating the sulfides. Copper ores are leached with water or weak acidic solution by four basic methods: dump leaching, where copper is extracted after leach solution percolation through low-grade waste; heap leaching, where the mined ore is placed on a plastic-, or asphalt-, lined pad for leach solution treatment; in situ leaching, where the leach solutions are applied directly to the ore body in the ground; and vat leaching, where the ore is first crushed and/or concentrated prior to placing it in a large vat or tank for leaching. Less commonly, sulfide ores may be roasted before being leached, to remove sulfur and facilitate copper leaching. Leaching may be followed by precipitation of the copper with scrap iron, producing precipitates or cement copper. Another concentration method involves passing the copper-bearing fluid from leaching through a series of solvent extraction steps using ion-exchange reagents to concentrate the copper content in a solvent, which is then treated electrolytically in electrowinning cells. A relatively high-grade copper cathode may be produced from this process.

Copper concentrates produced by milling and flotation may contain between 18% and 40% copper. Smelting concentrates and precipitates produces products such as matte, blister, anode and slag. Slag is the waste formed from smelting and, though it may contain small amounts of copper, it is high in silicon and iron. Copper matte contains between 15% and 65% copper, together with much of the sulfur and other nonferrous and precious metals. Copper matte is transferred to a converting furnace where the sulfur and iron are oxidized and removed as sulfur dioxide gas and slag,

respectively; the enriched copper metal (97% to 98.5% copper) is poured as blister copper. Blister is then deoxidized and poured into anode form. Anodes are then immersed in an electrolyte bath to form refined copper cathode through electrolysis. Valuable impurities, such as gold, selenium and silver are collected at the bottom of the electrolytic tank as a residue and are recovered in a later process. Refined copper cathode, which contains greater than 99.3% copper, is the predominant form traded on world markets.

Resources--The world copper reserve base totals 552 Mmt of contained copper, of which 321 Mmt may be considered reserves. Reserves are widely distributed throughout the world. Table IIIAiiib-2 lists the location of copper reserves and resources. In 1990, those countries with the largest share of reserves include Chile (26%), the United States (17%), the Soviet Union (12%), and Zaire (8%). The world reserve base increased by 140% from 1965 to 1976. Since 1976, however, the reserve base increased by only 20%. While significant reserve growth has occurred in countries such as Chile, Australia, and Indonesia from 1976 through 1990, countries such as Canada and the United States have exhibited a decrease or stagnation in copper reserves in recent years.

Several observations may be made concerning the deposits in the U.S. reserve base. Over half of the U.S. reserve base may be classified as currently economic; if these were the only source of copper to be mined, the U.S. would likely run out of copper in about 27 years. This is an unrealistic assumption, however, since many of the deposits in the identified resource will be mineable in the future. Even so, based on current estimates, the U.S. reserve base by 2020 will be less than one-half its current size. In addition, unless more large, low-grade, low-cost deposits amenable to open pit mining are discovered, U.S. copper mines of the future may be increasingly underground and higher cost. This contrasts with the current dominance (85% of capacity) of low-grade, open pit mines and leachable oxide deposits.

Analyses conducted on 110 producing Market Economy Country (MEC) copper properties evaluated the availability of 230 Mmt of copper. Table IIIAiiib-3 lists recoverable copper by country, along with average grade and production cost. It shows Chile with 77 Mmt of recoverable copper, the largest share of resources, at an average

[38] Internal report prepared by the U.S. Bureau of Mines' Commodity Specialist for Copper.

[39] Recoverable copper refers to currently producing mines. Reserves include facilities that need not be in place or operative. See definitions in Appendix 5.

production cost of $0.48/lb. copper. The United States is second with 32 Mmt at a cost of $0.57/lb. The average world production cost is $0.59/lb. Figure IIIAiiib-3 shows the availability of evaluated producing properties by operation. It indicates that two thirds of the recoverable copper is available for $0.60/lb. or less and 90% is available at under $0.80/lb.

Non-producing mines and deposits evaluated for availability contain another 106 Mmt of copper. The average cost of extracting these resources is estimated to be 50% higher than the current average cost of mining. Most prospective copper mine deposits are in South and North America, with Chile being the most important source.

Separate availability analyses performed in 1981 and 1988 provided a comparison of changing copper operating costs within a country. Figure IIIAiiib-4 shows that major producers, including the United States, have made significant improvements in mining and milling costs. In dollars adjusted for inflation, U.S. operating costs dropped from $1.33/lb. copper in 1981 to $0.62/lb. 1990. Canada and Australia showed comparable improvement, while costs in Chile and Mexico remained relatively low and steady. Both of the major producers in Africa, Zaire and Zambia, saw a doubling of operating costs.

World Production--In 1990, nearly 9 million tons of copper was mined in 54 countries with the top 11 producing nations accounting for over 80% of world production. Only 19% of copper mined was exported as concentrates; most was smelted and/or refined in the country where it was mined. Currently, Chile is the largest producer of copper followed closely by the United States. Canada, the U.S.S.R. and Zambia are other major producers. Figure IIIAiiib-5 shows world copper production more than doubled from 1960 through 1990.

National Defense Stockpile--Because the use of copper in all types of defense-related items in both military and civilian sectors escalates during times of national emergency, copper has always been of strategic importance in wartime planning. In order to assure a steady supply of copper during periods of shortage, the U.S. Government has used stockpile acquisitions and sales, allocation systems, and price controls. The National Defense Stockpile contained over 1 Mmt of copper until 1964 when a decision was made to reduce the stockpile goal and sell most of the copper. The first tier stockpile goal for copper is currently zero. Figure IIIAiiib-6 shows that initially the NDS was reduced to about 250 kmt until 1974 when the copper stockpile was reduced to 20,000 tons of refined copper. Copper stocks held in inventory

by industry climbed in response to the NDS sell off and was maintained at excessive levels to industry demands until 1987. Since 1987 industry and NDS stocks combined barely totalled 100 kmt. Figure IIIAiiib-6 further shows that during this latter period, the monthly average U.S. consumption of refined copper exceeded the total government and industry stocks by nearly 80%. Under this supply-demand condition, the weighted annual average producer price for refined copper increased by about 86%.

Security of Supply--While the United States is the second largest producer of copper, it is also the largest copper consuming nation in the world, a situation that will probably continue in the foreseeable future. Under ordinary circumstances, the United States is largely self sufficient in copper. In time of war or other emergency, Canada, Mexico, and Chile are major sources for copper imports. The current North American Free Trade Agreements and free trade negotiations with Chile that are underway may pave the way for easier commodity flow in times of emergency.

Uncertainty and disruption of supply has been a hallmark of copper production throughout history. When a large mine shuts down unexpectedly, as did the Bougainville Mine in Papua New Guinea in 1989, the market effect is significant. (Large mines are those with capacity production over 100,000 my/year. The 29 copper mines classified as large account for 60% of MEC mine capacity production.) In previous years, stockpiles of copper served as a buffer for supply disruptions, such as the nine month labor strike of the late 1960's. Current stockpile levels are expected to continue to be minimal, and so, cannot be relied upon in the future.

Environmental Concerns--The primary environmental concern related to copper mining is the potential for surface and groundwater contamination with acid rock drainage. Acid rock drainage occurs as a result of the natural oxidation of sulfide minerals as they are exposed to air and water. The potential for this may exist long after the mine is closed when the mine, previously protected by pumping, is allowed to fill with water. Mine pits, underground workings, overburden and waste piles, tailings ponds and spent leach piles may be sources of water contaminants, if not properly protected. Leachate solutions used for leach recovery of copper may be released from active dump leach piles or ponds during large storm episodes. These solutions may be acidic and contain high concentrations of copper.

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[40] Calculated from data appearing in the U.S.B.M. 1990 Annual Report, Copper chapter.

In recent years, the copper industry has taken a proactive stance toward environmental problems with many new approaches to solving them. In 1991, International Council on Metals and the Environment (ICME) was formed with 14 major mining companies in an effort to coordinate industry knowledge, experience and resources to address international issues. The copper industry anticipated becoming more active in developing and implementing sound environmental and health policies and practices. All mines have health and safety staffs who are charged with careful monitoring of all potential hazards. The requirement for financial assurance has become commonplace to assure proper closure of a mine. Responsibility for monitoring potential environmental effects continue long after the mine is closed.

Mitigation procedures used for preventing potential environmental problems start with proper design of the mining and milling facilities so that both physical impacts on the habitat and functional impairment of the ecosystems are minimized. Ponds and leach or dump pads are lined with clay or synthetic liners. Draft contingency plans are made for catastrophic releases, and water systems are recirculated, or are treated to reduce acid and other contaminants. Mine reclamation includes removal of all mills and other facilities as well as recontouring and reclamation of waste and tailings dumps. The dumps, tailings or ponds may be covered with nets or other cover during operation. Acid mine drainage may be controlled by treatment with lime neutralization or other techniques.

Special Issues Related to Forest Lands--Large, undeveloped copper deposits occur on Forest Service lands. Many of the deposits that could be mined in the near future are located in the western states, where availability of public lands for mineral development has, in many cases, been severely restricted.

A recent attempt, for example, to affect a land exchange for the eventual development of an open pit copper mine in the Prescott National Forest in Arizona was delayed indefinitely because of environmental concerns. The cost of the required impact study, estimated at $2.5 million, was considered to be prohibitive by the mining company.

Present efforts by the private sector to develop large copper-silver reserves in the Cabinet Mountains Wilderness of the Kootenai National Forest of Montana have been delayed primarily because of potential surface-water contamination. State law does not allow any increase of regulated wastes or contaminants to be discharged into surface drainage, even though the increased level of contamination may be within acceptable prescribed limits.

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[41] Inventory of Land Use Restraints (ILURP) reports. U.S. Bureau of Mines.

Construction Sand and Gravel

Sand and gravel, as one of the most accessible natural resources, has been used since the earliest days of civilization, mostly as a construction material. At the beginning of the 20th century, the U.S. production of construction sand and gravel, the sand and gravel used mostly for construction purposes, was relatively small and its uses limited. Today, annual sand and gravel production tonnage ranks second in the nonfuel minerals industry after crushed stone, and is the only mineral commodity produced in all 50 States. The United States is, in general, self-sufficient in sand and gravel, producing enough to meet all domestic needs and to be a small net exporter, mainly to consumption points along the United States-Canadian and United States-Mexican borders.

Sand and gravel is a granular, unconsolidated, and usually rounded agglomeration of particles of rocks and minerals, resulting primarily from the natural disintegration and abrasion of rocks through weathering or erosion. Sand and gravel is mostly used for construction purposes, and because of that it is defined as construction sand and gravel. Its main uses are as aggregate in concrete; as road base material in the construction and repair of highways, railways, and runways; and as aggregate in asphaltic concrete for paving highways, streets, etc. Construction sand and gravel has one of the lowest average unit values of all mineral commodities and it is characterized by its "place value," a term that describes the importance of the location of the geologic deposit in reference to the market. Crushed stone and to a lesser extent iron-blast-furnace slag and steel slag are the predominant substitutes for construction sand and gravel used as construction aggregate.

Demand--The demand for construction sand and gravel is determined mostly by the level of construction activity and therefore the demand for construction materials. U.S. production of construction sand and gravel recorded a significant growth in the last 40 years, from 320 million metric tons in 1950 to 826 million metric tons in 1990. The highest level of production was reached in 1978 with 874 million short tons.

Between 1950 and 1966, due to the construction of the Interstate Highway System, the growth from year to year in the production of construction sand and gravel was almost continuous, paralleling the increased demand for

construction aggregates. Following reduction in the Interstate Highway Program during the late 1960's, the construction sand and gravel industry became more sensitive to the ups and downs of the economy. The 1974-75 and 1982 recessions are well reflected by low levels of production of construction sand and gravel in those years. Figure IIIAiiic-1 shows the highly variable nature of crushed stone production/consumption for the years 1964 through 1990.

Future demand for sand and gravel will continue to be dependent mostly on changes in construction activity. For the period 1990 to 2000, the demand for sand and gravel is expected to grow at an average annual rate of about 1%. However, from 2000 to 2040, sand and gravel is expected to grow at the lower average annual rate of 0.5%. Figure IIIAiiic-2 contains the historical and forecast demand for sand and gravel in the United States.

Geology--Sand and gravel deposits are the result of the erosion of bedrock and the subsequent transport, abrasion, and sedimentation of the particles by water, ice, or wind. The processes of formation and deposition impart to sand and gravel the physical characteristics that largely determine the commercial value for a particular use and influence the manner of development. The principal types, based on origin, are stream, glacial, residual, marine, and lake. Windblown deposits are of minor importance. Much of the commercial production is from stream deposits, many of which are deficient in the fines required by present-day grading specifications for concrete aggregates. Stream deposits usually exhibit stratification and often large size gradation. The beds vary in thickness and sometimes have interspersed lenses of clay or fine sand. The degree of roundness and the particle size varies with the hardness and distance transported. Glacial deposits have the least sorting of all transported deposits, while marine and lake deposits exhibit the best sorting with coarse and fine particles, often well segregated. Residual deposits are found overlying the parent rock and are unstratified mixtures of pebbles, boulders, sand, and clay. They often contain much soft material that prohibits commercial production. Marine or offshore deposits could become more important as inland deposits become depleted or environmentally less desirable to extract.

Mining and Processing Technology--Sand and gravel generally occur in the same deposit, but the relative proportions of each vary greatly within most deposits. Consequently, the control problem of producing aggregate to rigid specifications involves combinations of many types of equipment like screens, washers, classifiers, crushers, and grinding

mills. The two basic sand and gravel mining methods are open pit excavation and dredging. Open pit excavation and processing has four major steps: (1) site clearing--removing trees and vegetation, stripping overburden and topsoil, and transporting, redepositing, or stockpiling it at or off the site; (2) mining--removing the sand and gravel from the deposit; (3) processing--screening, washing, crushing, blending, and stockpiling the mined material to conform to standards and specifications; and (4) reclamation of the extraction area. Processing may or may not take place at the mining site. Mining equipment ranges from small, simple units such as tractor-mounted high-loaders and dump trucks to more sophisticated systems involving large power shovels, draglines, bucketwheel excavators, and belt conveyors. Increasingly, mining systems are being designed to provide for more efficient and economical land reclamation. Mining with a dredge usually involves mounting the equipment on boats or barges. Suction or bucket-type dredges are used most commonly to harvest sand and gravel from the bottom of a body of water. The sand and gravel is processed either on board or transported to land for processing.

Although small amounts of unprocessed bank-run sand and gravel are used for fill, most of the U.S. production is processed in some way. Present methods include washing with water during the screening process, in some cases followed by crushing of the larger particles in cone or gyratory crushers. Secondary crushing may be done by roll crushers. Sizing is done, in most plants by horizontal or sloped single or multideck vibratory screens. If necessary, heavy-media separation or jigging is used to remove heavy, unusable materials. Sand for use in construction is freed from clay by log washers or rotary scrubbers. The scrubbing is followed by classification, use of separatory cones or hydroseparators to remove water, and fine screening for grading. Rodmilling is often required for production of small-sized fractions of sand. Transfer of processed sand and gravel from the processing plant to stockpiles or bins is accomplished by flexible combinations of conveyor belts, bucket elevators, and screw conveyors.

Permanent installations are built when large deposits are to be operated for many years. Portable and semiportable units are used in many pits that have an intermediate working life. Several such units can be tied together to obtain large initial production capacity or to add capacity as needed. Mobile screening plants can be quickly moved from one deposit to another without undue interruption or loss of production.

Resources--On the basis of geologic evidence, construction sand and gravel resources of the United States and

the world are in general sufficient to meet demands, although not always precisely at the locations where needed. Reserves, which are measurable amounts of construction sand and gravel that can be produced profitably with current technology under existing economic and political conditions, are controlled mostly by land use and/or environmental constraints. The actual volume of construction sand and gravel available is vast and therefore measurement of reserves on a large scale is not a practical exercise. The local shortages that occasionally exist are caused less by a lack of sand and gravel than by urban encroachment or zoning regulations that force closure of operations or prevent the development of new ones. In the United States, construction sand and gravel is produced in every State which is a clear indication of its availability. The largest operations tend to be concentrated in the States with the largest population and largest production of sand and gravel. On a global scale, construction sand and gravel is produced in virtually all countries, but relatively few of them survey this industry and even fewer regularly publish official statistics on sand and gravel.

A comprehensive report describing geologic occurrences of potential sources of sand and gravel and crushed stone of the conterminous United States for use as natural aggregates was published by the U.S. Geological Survey.

World Production--The widespread distribution of domestic sand and gravel deposits and the high cost of transportation limits foreign trade mostly to local transactions across international boundaries. U.S. imports and exports are small, representing only about 1% of the domestic consumption. The U.S. Bureau of Mines does not maintain world production figures for construction sand and gravel.

National Defense Stockpile--Construction sand and gravel is not included in the National Defense Stockpile, nor is it expected to be.

Security of Supply--Construction sand and gravel is a high-volume, low-value commodity. The industry is highly competitive and is characterized by thousands of operations serving local or regional markets. Production costs vary widely depending on geographic location, the nature of the deposit, and the number and type of products produced. Constant dollar unit values have been quite steady during the past 20 years. As a result of rising costs of labor, energy,

[42] Langer, W.H. Natural Aggregates of the conterminous United States. U.S. Geological Survey Bulletin 1594.

and mining and processing equipment, the average unit price of construction sand and gravel increased from $1.1 per ton, f.o.b. plant, in 1970 to $3.57 in 1990. However, the unit price in constant 1982 dollars fluctuated between $2.64 and $2.71 per ton for the same period. Increased productivity achieved through increased use of automation and more efficient equipment was mainly responsible for maintaining the prices at this level. Constant dollar prices are expected to rise in the future because of decreased deposit quality and more stringent environmental and land use regulations.

Accessibility is a problem for the construction sand and gravel industry. The high-volume and low-unit value of sand and gravel requires that operations be close to the market location. Markets for sand and gravel are construction sites that are mostly in areas of high population density. New operations, close to population centers, are difficult to develop because the land is often attractive for other uses such as housing, shopping centers, agriculture, parks or recreational areas, and because of public dislike for mining operations close to populated areas. Existing operations in expanding communities face increasing costs because of increasing land values and increasing restrictions on operations as suburban development comes closer. Deposits are often small and, once exhausted, the operation must be moved to a new site that invariably is farther from the market because closer sites are being used for other purposes.

The industry also faces increasing competition from crushed stone that can substitute for sand and gravel in most of its applications. Stone operations are generally longer-lived, can afford greater capital investment for higher efficiency, and are often located where competing land use pressures are less severe. The topographically rugged stone-bearing areas are usually less desirable for construction purposes than sand-and-gravel-bearing areas, which are generally flatter.

Although construction sand and gravel resources are widespread and in adequate supply nationally, local shortages exist. Land use conflicts and environmental problems associated with rapid urban expansion are major factors contributing to these shortages. In addition, in some geographic areas with sufficient resources, some shortages occur because the proportions of various size fractions of sand or gravel may not meet size specifications of the construction industry. Demand pressures, land use regulations, and the cost of meeting environmental and reclamation requirements are factors that will cause a rising price trend. Larger operations with more efficient equipment, more automation, and better planning and design will be the trend of the industry in the future. This will permit increased use of less accessible and lower quality deposits and will keep prices at competitive levels.

Transportation is a major factor in the delivered price of construction sand and gravel. The cost of moving

construction sand and gravel from the plant to the market often exceeds the sales price of the product at the plant. Because of the high cost of transportation, construction sand and gravel continues to be marketed locally. Economies of scale, which might be realized if fewer, larger operations served larger marketing areas, would probably not offset the increased transportation costs. Truck haulage is the main form of transportation used in the construction sand and gravel industry. Many producers have their own truck fleet and deliver their own raw materials and products. A significant and increasing amount of sand and gravel, however, is being hauled by independent truckers because of the cost of maintaining a truck fleet, particularly when the market is highly variable or down. Rail and water transportation combined account for about 10% to 20% of total construction sand and gravel shipments.

Environmental Concerns--Although much progress is being made through premining planning, the sand and gravel industry continues to have problems with environmental controls, land use conflicts, and reclamation practices. Many of these problems are acute because extraction areas and plants must be reasonably near to consumers who are largely in metropolitan areas. Major environmental considerations that must be dealt with in mining and processing sand and gravel are emission of particulate matter into the air, processing water discharge, noise abatement, and employee and public health and safety. The industry must be concerned about any practices that can affect the community environment. An effective effort must be made to reduce noise, air, and water pollution; to reclaim pits after the operation is complete; and to improve the overall appearance of the operating mine, processing plant, and transportation facilities. Second, the industry and community must recognize the time and costs required to protect the environment and the importance of agreeing on fair and realistic environmental standards.

Because sand and gravel is a local commodity, the effect of supply deficiencies and cost of material will affect the local community first. Undue delay and unreasonably high cost can strongly affect the movement of sand and gravel into the marketplace. Also, stringent controls by the local government that prevent permits being issued to operators can have adverse economic effects on the communities around them. These conditions can make it difficult to assess the timing and even the possibility of plants going on-stream and can therefore affect the supply of sand and gravel into the marketplace.

Construction sand and gravel remains an abundant material and despite environmental, zoning, and regulatory restrictions, no major shortages at the National level are expected to occur in the future. At the same time shortages in

and near urban and industrialized areas which usually represent major markets are expected to continue to increase.

Special Issues Related to Forest Lands--Abundant resources of sand and gravel occur on Forest Service lands. These resources, however, contribute only a small percentage of the total construction sand and gravel produced in the U.S.

Issues common to the construction sand and gravel industry, including environmental concerns and zoning requirements, are local in nature and do not have a large effect on total domestic production. Although these issues may affect development of sand and gravel reserves on certain Forest lands, the impact will be limited and will be compensated generally by the presence of alternative sources in the region.

Crushed Stone

Crushed stone (CS) is a term applied to rock that has been broken and/or crushed after quarrying. It is a low-value product characterized by its "place value," a term that describes the importance of the location of the geologic deposit in reference to the market. Most crushed stone is used for construction purposes, mainly as aggregate, with or without a binder. Road base or road surfacing material, macadam, riprap, and railroad ballast are the major uses without a binder. Aggregate for cement and bituminous concrete in highway and road construction and repair and in residential and nonresidential construction are the major uses for aggregates with a binder. Other uses include cement and lime manufacture, agriculture, metallurgical flux, and fillers and extenders.

Sand and gravel, and to a lesser extent iron-blast-furnace slag, are the predominant substitutes for crushed stone used as construction aggregate. Steel slag is another substitute for crushed stone in road bases and asphaltic concrete, but not in cement concretes because of chemical interactions. Blast-furnace slag is also used as a stone substitute in cement manufacturing.

Demand--The demand for crushed stone is determined mostly by the level of construction activity and, therefore, the demand for construction materials. U.S. production of crushed stone recorded a significant growth in the last 40

years, from 229 million metric tons in 1950 to 1.1 billion tons in 1990. The highest level of production was 1.13 billion tons, reached in 1988. Between 1950 and 1973, due to the construction of the Interstate Highway System, the yearly growth in the production of crushed stone was almost continuous, paralleling the increased demand for construction aggregates. Following the reduction in the Interstate Highway Program in the late 1960's, the crushed stone industry, while still growing, became more sensitive to the ups and downs of the economy. The 1974-75 and 1982 recessions are well reflected by low levels of production of crushed stone in those years. Figure IIIAiiid-1 shows the highly variable nature of crushed stone production/apparent consumption for the years 1964 through 1990.

Future demand for crushed stone will continue to be dependent mostly on changes in construction activity. For the period 1990 to 2000, the demand for crushed stone is expected to grow at an average annual rate of about 2%. However, from 2000 to 2040, the demand for crushed stone is expected to grow at the lower average annual rate of 1%. Figure IIIAiiid-2 contains the historical and forecast demand for crushed stone in the United States.

Geology--Rocks in the earth's crust are classified into three types based on their origin: igneous, metamorphic, and sedimentary rocks. Igneous rocks, which solidify from earth's molten or partially molten magma, are classified by origin and mineralogy. Intrusive rocks are igneous rocks formed within the Earth, and include granite, diorite, and gabbro as the rock types. Volcanic or extrusive rocks are igneous rocks that have been ejected onto the Earth's surface, and include rhyolite, andesite, and basalt (trap rock). Igneous rocks are usually hard, tough, and dense, with the exception of tuffs and certain lavas that are very porous.

Metamorphic rocks are derived from preexisting rocks that have been modified by high temperature and pressure (stress) within the Earth's crust, and include schists, gneisses, slates, marbles, and quartzites. The physical characteristics of metamorphic rocks vary widely from dense, hard, and strong (marbles, gneisses, and quartzite,) to laminated and friable (some schists and slates.)

Sedimentary rocks are rocks resulting from the consolidation of loose sediments, some chemically or biochemically deposited like limestone, dolomite, and chert, and others mechanically deposited like conglomerates, sandstone, siltstone and shales. Sedimentary rocks commonly occur in layers and their physical characteristics varies from strong to weak, hard to soft, and dense to porous.

The terminology used by the crushed stone industry is not always consistent with the mineralogical definitions. Limestone and dolomite are rocks composed, respectively, of the minerals calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$); however, they are usually called limestone by the industry, and intermediate varieties are seldom distinguished. Some deposits of limestone consist chiefly of the mineral aragonite, which has the same composition as calcite, but has a different crystal structure. Marble may include any calcareous rock that will accept a polish. Marl is calcitic and contains varying amounts of shale or clay. Granite includes the coarser grained igneous rocks such as true granite and syenite. Gneisses, although metamorphic rocks, are usually included with granite. Quartzite is a well-cemented sandstone that is indurated to the extent that, when fractured, it breaks across the grain. Traprock includes all dense, dark, and fine-grained igneous rocks such as basalt, diabase, and gabbro.

Mining and Processing Technology--Most crushed and broken stone is mined from open quarries; however, in many areas, factors favoring large-scale production by underground mining are becoming more frequent and more prominent. Surface mining equipment varies with the kind of stone mined, the production capacity needed, the size and shape of the deposit, estimated life of the operation, location of the deposit with respect to urban centers, and other important factors. Ordinarily, drilling is done with tricone rotary drills, long-hole percussion drills, and churn drills. Blasting in smaller operations may still be done with dynamite, but in most medium- to large-size operations ammonium nitrate-fuel oil mixtures (AN-FO), which are much lower in cost, are used.

Underground operations are becoming more common, especially for limestone mining in the central and eastern parts of the United States, as the advantages of such operations are increasingly recognized by the producers. By operating underground, a variety of problems usually connected with surface mining, such as environmental impacts and community acceptance, are significantly reduced. Underground room-and-pillar mines can be operated on a year-round basis, do not require extensive removal of overburden, and produce a minimum of surface disturbance. A specific advantage of underground quarries is the creation of valuable storage facilities. In many cases, the value of the sale or rental of the storage space may exceed the value of the stone mined.

Loading and hauling equipment has grown larger as increased demand for stone has made higher production capacities necessary. Track-mounted equipment is still used extensively, but hydraulic, tire-mounted hauling equipment is

predominant.

Processing plants have become larger and more efficient, in part because of an increase in the use of computerized control systems. Programmable controllers and/or computers are viewed today as valuable tools that improve operating efficiency and product quality. Primary crushing is often done at or near the pit, usually by jaw or gyratory crushers, but impact and other special types of crushers are also used for nonabrasive stone or stone that tends to clog conventional crushers. The cost effectiveness of permanent crushing installations can be limited because, as mining moves away from the primary crusher, it becomes increasingly expensive to haul material from the production face to the crushing plant. Improved crusher technology and increased capacity toward greater equipment mobility are accelerating the use of in-pit movable primary crushers. There is an increased interest in the use of portable crushers ranging in size from 500 tph up to 5,000 tph. For secondary crushing, a variety of comminution equipment is used, depending on plant size, rock type, and kind of material being produced. Cone crushers and gyratory crushers are the most common types used, but impact crushers, including hammer mills, and roll crushers are often used. Belt conveyors are being used extensively to haul material within the quarry because they provide continuous operation, low maintenance costs, low work force requirements, and reduced noise levels. Conveying systems are often associated with in-pit crushers and consist of several portable units and a stationary field conveyor. The portable conveyors, usually in 100 to 200 ft. lengths make the connection between the portable crusher and the field conveyor and provide a good range of motion. The increased use of conveyors reduces significantly the use of haul trucks in quarries.

Screening is the single most important part of the processing cycle of crushed stone particles. A wide variety of screen types exists, and their selection is a function of the material processed as well as the final product required. Inclined vibratory screens are most commonly used in stationary installations, while horizontal screens are used extensively in portable plants. For screening large sizes of crushed stone, grizzly bars, rod decks, and heavy punched steel or plastic plates are used; for smaller sizes, woven wire, welded wire cloth, rubber, or plastic screens are used.

Processed crushed stone is usually stored in open areas, except for relatively small quantities that go to the load-out bins. In the more efficient plants, the crushed stone is transported from the storage piles on belt conveyors through tunnels installed under the piles, thus facilitating the blending of any desired mixture of sizes from different piles.

Resources--On the basis of geologic evidence, stone resources of the United States and the world are sufficient to meet demands, although not always precisely at the locations where needed. Reserves, which are measurable amounts of crushed stone that can be produced profitably with current technology under existing economic and political conditions, are controlled mostly by land use and/or environmental constraints. The actual volume of stone available is so vast as to preclude the necessity of measurement on a large scale. The local shortages that occasionally exist are caused less by a lack of stone than by urban encroachment or zoning regulations that force closure of operating quarries or prevent the development of new ones.

Granite and traprock are the most common igneous rock-types used as crushed stone. Granite occurs primarily in the eastern part of the United States from Maine to Georgia, along the Appalachian Range where major producing States are located. It also occurs in Arkansas, Minnesota, Missouri, Oklahoma, Texas, and Wisconsin and in all Western States except Utah. Most of the traprock occurs in California, Hawaii, Idaho, Oregon, and Washington in the West, in Connecticut, Maryland, Massachusetts, New Jersey, New York, North Carolina, Pennsylvania, and Virginia in the East, and to a smaller extent in Minnesota and Texas.

Marble, quartzite, and slate are the major types of metamorphic rocks used to some extent as crushed stone. Marble occurs primarily in Alabama, Georgia, New York, Vermont, and Virginia in the East and in California and Texas in the West. Limestone and dolomite are widespread throughout the conterminous United States, but significant deposits are located in the midcontinent, especially in Kentucky, Tennessee, and Missouri, and in the States adjacent to the Great Lakes.

A comprehensive report showing geologic occurrences of potential sources of crushed stone and sand and gravel of the conterminous United States for use as natural aggregates was published by the U.S. Geological Survey.

World Production--The widespread distribution of domestic crushed stone deposits and the high cost of transportation limits foreign trade mostly to local transactions across international boundaries. U.S. imports and exports are small, representing less than 0.5% of the domestic consumption; however, shipments of crushed stone by water from Canada and Mexico are increasing. The U.S. Bureau of Mines does not maintain world production figures for crushed

[43] Langer, W.H. Natural Aggregates of the Conterminous United States. U.S. Geological Survey Bulletin 1594.

stone.

National Defense Stockpile--Crushed stone is not included in the National Defense Stockpile, nor is it expected to be.

Security of Supply--Crushed stone is a high-volume, low-value commodity. The industry is highly competitive and is characterized by thousands of operations serving local or regional markets. Production costs are determined mainly by the cost of labor, equipment, energy, and water, in addition to the costs of compliance with environmental and safety regulations. These costs vary depending on geographic location, the nature of the deposit, and the number and type of products produced. Despite having one of the lowest average per ton values of all mineral commodities, the constant dollar price of crushed stone has changed relatively little over the past 20 years. As a result of rising costs of labor, energy, and mining and processing equipment, the average unit price of crushed stone increased from $1.58 per ton, f.o.b. plant, in 1970 to $4.39 in 1990. However, the unit price in constant 1982 dollars fluctuated between $3.48 and $3.91 per ton for the same period. Increased productivity achieved through increased use of automation and more efficient equipment was mainly responsible for maintaining the prices at this level.

The delivered price of the product, in addition to quality, is a particularly important element in any major transaction because of the low unit value of crushed stone, and therefore, producers that are closest to markets have a significant advantage. Sophisticated equipment backed by technical knowledge combined with solid sales expertise are becoming very important. For this reason, large companies are better able to compete in the crushed stone business, especially when there is a need for a wide variety of products. Smaller, less efficient operations become less economical as operating costs, as well as costs associated with meeting various Federal, State and local regulations, continue to increase. The only alternatives these producers have are to supply local markets with a limited number of products. The gradual trend toward larger operations has continued, mostly because the stone industry is capital intensive, and it is becoming less economical to operate small quarries. The viability of small operations is dependent on the demand in the local markets, mining costs, and the degree of processing required to supply the final product.

Transportation is a major factor in the delivered price of crushed stone. The cost of moving crushed stone from

the plant to the market often equals or exceeds the sales price of the product at the plant. Because of the high cost of transportation and the large quantities of bulk material that have to be shipped, crushed stone is usually marketed locally. The high cost of transportation is responsible for the wide dispersion of quarries around the country, usually located near highly populated areas. However, increasing land values combined with local environmental concerns are moving crushed stone quarries farther from the end-use locations, increasing the price of delivered material. Economies of scale, which might be realized if fewer, larger operations served larger marketing areas, would probably not offset the increased transportation costs.

Truck haulage is the main form of transportation used in the crushed stone industry, despite the fact that it is the most expensive mode of transportation on a cost-per-ton per-mile basis. Many producers have their own truck fleet and deliver their own raw materials and products. A significant and increasing amount of crushed stone, however, is being hauled by independent truckers because of the cost of maintaining a truck fleet, particularly when the market is highly variable. Rail and water transportation combined account for about 7% to 10% of total crushed stone shipments. In recent years an increased amount of crushed stone is being shipped into the U.S. by water from Canada and Mexico, using large ocean going vessels. Some of these are self-unloading vessels.

Environmental Concerns--Many of the environmental problems facing crushed stone producers arise because a great number of stone quarries and processing plants are located in suburban areas near the major crushed stone markets. Major environmental considerations that must be dealt with in mining and processing of crushed stone are emission of particulate matter into the air, discharge of processing water, noise abatement, and employee and public health and safety. Air pollution constitutes a major problem in processing plants, especially in the drying and packaging stages of fine particle products such as limestone used as fillers or extenders. Both wet and dry methods of dust control are used. The most important water pollutant is clay in suspension that results from washing and screening crushed stone. Because of the large quantities of water used to process stone and the need for compliance with often stringent regulations, the treatment of discharge water by crushed stone producers is becoming a necessity that may require sophisticated and expensive processing methods. Significant progress has been made in reducing noise pollution both inside and outside of the quarries, including noise and vibration produced by blasting and movement of heavy trucks. Because crushed stone is

a local industry, the effect of supply deficiencies and cost of material will affect the local community first. Undue delay and unreasonably high cost can strongly affect the movement of crushed stone into the marketplace. Also, stringent controls by the local governments that prevent permits being issued to operators can have adverse economic effects on the communities around them. These conditions can make it difficult to assess the timing and even the possibility of plants going on-stream and can therefore affect the supply of crushed stone into the marketplace.

Stone remains an abundant material and despite environmental, zoning, and regulatory restrictions, no shortages on a large scale are expected to occur in the future.

Special Issues Related to Forest Lands--Abundant resources of stone suitable for the production of aggregate occur on Forest lands. These resources, however, contribute only a small percentage of the total crushed stone produced in the U.S.

Issues common to the crushed stone industry, including environmental concerns and zoning requirements, are local in nature and do not have a large impact on total domestic production. Although these issues may affect development of stone reserves on certain Forest lands, the impact will be limited and will be compensated generally by the presence of alternative sources in the region.

Gold

Gold lore and the use of gold predates written history. Because of its beauty and permanence gold has been considered a precious metal since ancient times and the mystique and folklore associated with gold has been a part of the fabric of civilized society throughout history. Similarly, the search for gold has stimulated world exploration and trade for more than six thousand years. The chemical symbol for gold is Au, from the latin word aurum, meaning "shining dawn."

Most of the gold that is fabricated today goes into the manufacture of jewelry. However, because of other desirable combinations of physical and chemical properties, gold also emerged in the late 20th century as an essential industrial metal. Gold performs critical functions in computers, spacecraft, and a host of other products.

Although gold is important to industry and the arts, it also retains a unique status among all commodities as a

long-term store of value. It was, until recent times considered essentially a monetary metal, and most of the bullion produced each year went into the vaults of government treasuries or central banks.

Demand--The production/apparent consumption of gold in the domestic market is shown in Figure IIIAiiie-1. During the period from 1934 to 1968 the price of gold was fixed at $35 per ounce and gold destined for use in the domestic market was supplied to commercial users from stocks held by the U.S. Treasury; there were also no direct imports to the U.S. market. Since the elimination of regulations on the private ownership of gold at the end of 1974 the demand for gold in the domestic market has been satisfied by the open market where gold from a variety of sources is bought, sold, and traded. In terms of the quantity of gold consumed in the domestic market, jewelry has always been the most important end use. Although the relative importance of jewelry declined somewhat in the 1950's and 1960's as industrial usage grew, and despite the generally rising price of gold during the last two decades, 57% of the gold consumed in the United States over the last decade was used in jewelry applications. During the same period dental applications absorbed 9%, while the remainder, 34%, was used in various industrial applications, principally electronic products.

Gold, as both an industrial mineral and a standard of value, is more or less unique among the mineral commodities in that a large proportion of all the gold ever produced still exists, generally in a market-ready refined form, as official stocks of central banks and as privately held coin, bullion, and jewelry. Thus, the fundamental elements governing the demand for gold are so different from those of other minerals that forecasting demand beyond the foreseeable future is extremely difficult. However, assuming that there is no significant change in the current U.S. standard of living or in Government monetary policies affecting gold or long-term shifts in consumer tastes in the all-important jewelry and electronics demand sectors, the U.S. consumption of gold for industry and arts is forecast to grow at an average rate of about 2% annually to the year 2040. See Figure IIIAiiie-2.

Geology--Gold deposits are found in many kinds of rock. Hydrothermal deposits appear to be somewhat more common in acidic and intermediate igneous rocks, in silty, laminated carbonate rocks, and in silicious or aluminous sedimentary or metamorphic rocks. The general deposit types include hydrothermal, hydrothermal-metamorphic,

metamorphic, replacement (lode, massive, and disseminated), and cavity filling (fissures, stockworks, saddle reefs, breccias, and conglomerates).

Gold occurs mainly as native metal, alloyed with silver and/or other metals, and as tellurides. Gold is commonly associated with the sulfides of iron, silver, arsenic, antimony, and copper.

Chemical and mechanical weathering and erosion cause gold in the free or metallic form to be released from lode or primary deposits and to accumulate as nuggets and grains in residual deposits or placer deposits. Although the richest lode gold deposits have been small fissure vein types with quartz gangue, the so-called bonanzas, much larger quantities of gold have been mined from large, medium-grade deposits.

Mining and Processing Technology--The technology of gold mining is well established, having evolved largely over the past century. Much of the world's gold production has come from deep narrow veins or from thin-bedded layers called reefs; these have been difficult to mine (in the Republic South Africa, for example) because of high underground temperature and humidity, and extreme rock pressure, which often causes dangerous rock bursts. Most domestic gold production comes from surface lode mines.

Placer mining was once an important source of gold. Dredging offers the maximum efficiency in large alluvial or marine deposits; dragline, hydraulic or bulldozing methods are commonly used in smaller, bouldery deposits such as those mined in some areas of Alaska. The South African mining industry, a leader in deep-mining technology for many years, has evolved new methods of controlling problems relating to rock stress, dust, and virgin rock temperature.

Table IIIAiiie-1 summarizes ore tonnages and gold production amounts, circa 1989, for surface mining operations in the United States and Australia and for underground mining operations in South Africa, Canada, and the United States.

Milling technology for gold is highly developed, and normal processing recovery rates range from 60% to 96%. Gold is recovered by cyanide leaching of gold ore contained in tanks or heaped on impervious leaching pads, by amalgamation, flotation, gravity concentration, and smelting, or by a combination of these processes. Increased exploitation of gold-bearing sulfide ores has led to the development and application of several technologies designed to render sulfide and refractory ores amenable to cyanide leaching.

Many gold mining operations recover gold from cyanide leach solutions by precipitation with zinc dust, though in recent years, activated carbon recovery technology has been adopted at most new mining operations. Gold with accompanying silver is desorbed or stripped from the carbon with a strong alkaline cyanide-alcohol solution. The precious metals are recovered from the strip solutions by electrodeposition on a stainless steel wool cathode. The cathode deposit is then refined into dore bullion, a mixture of mostly gold and silver.

Gold leaching processes in use or under development that do not employ cyanide as the principal lixiviant or dissolution medium include the application of thiourea, iodine, malonitrile or various bioextraction techniques. Some of these alternate techniques, unlike the long-established, well-understood cyanide process may be accompanied by unacceptable cost or environmental burdens. Gold is refined by chlorination in the molten state (Miller process) and by electrolysis (Wohlwill process). Generally, gold bullion made by the Miller process is 996 to 997 fine, and bullion made by the Wohlwill process is 999.5 to 999.8 fine.

Resources--Table IIIAiiie-2 lists worldwide reserves and the reserve base for gold. Demonstrated U.S. reserves of gold are about 4,770 mt and the reserve base is 5,250 mt.

Most of the U.S. gold reserve base shown in Table IIIAiiie-2 is confined to 18 states, with about 80% of the total in Alaska, California, Idaho, Montana, Nevada and Washington. A dominant portion of the reserve base occurs in lode deposits.

Total world reserves shown in the Table IIIAiiie-2 approximate 43,000 mt of which nearly one-half are in the Republic of South Africa. The world reserve base for gold totals about 49,500 mt. Reserves of gold in the former U.S.S.R. are believed to be about 6,220 mt.

Total world resources of gold are estimated at 74,600 mt, of which 15% to 20% are byproduct resources. The Republic of South Africa has about one-half of the world resources, and Brazil, the former U.S.S.R., and the United States about 12% each. Some of the 9,000-ton U.S. resource would be recovered as byproduct gold.

A comparison of average, 1989 "direct operating costs" for the major market economy gold producing countries shows the U.S. at $6,910/kg, Canada at $8,000/kg, South Africa at $8,910/kg, and Australia at $9,260/kg. However, the

[44]Metal Market Consultants, Inc. Gold Situation 1990. Lakewood, Colorado 1990.

major surface mining operations in the U.S., accounting for about 83% of total U.S. lode gold production in 1989, have an average life of only about 8 years. The Canadian underground producers, as of 1989, also have an average life of about 8 years. The Australian producers, which are mostly surface mining operations, average only about 5 years life, as of the end of 1989.

World Production--World gold mine production at 2,050 mt in 1990, registered the eleventh consecutive year of positive growth. During 1990, actual or estimated production data as shown in Figure IIIAiiie-3 was recorded for nearly 70 countries.

U.S. gold production from its beginning in the 18th century to date totals about 11,300 tons. The principal producing States, in declining order of cumulative production are: California, Nevada, Colorado, South Dakota, Alaska, Utah, and Montana; the remainder came from 11 other States.

Gold mining in Australia began about 1849 as an off-shoot of the California gold rush. Russian gold mining had been expanding since the mid-18th century, and by the eve of the California gold rush, Russia was producing nearly two-thirds of the world's gold. Gold mining in South Africa started in the 1870's. Because of the size, diversity, and explosive growth of primary gold production over the past decade, comprehensive world production capacity data that would include all operating units that contribute to national totals are generally not available.

Because of its high intrinsic value, gold has been recycled throughout the ages. Precious metals refiners throughout the world recover gold from scrap. In the United States, about 60% of the scrap comes from current manufacturing operations, and the remainder comes from old scrap.

The substantial annual rates of growth in world mine production recorded during the decade of the 1980's are anticipated to slow considerably during the decade of the 1990's. Gold production in some major gold producing nations such as the former U.S.S.R. and the Republic of South Africa may decline substantially as technical, political and/or economic factors intervene to hinder mine development.

In other nations such as Australia, Canada, and the United States, peak in production may be reached in the early to mid 1990's and remain at or near peak levels for the remainder of the century. Many less developed nations may continue to expand production as new mining laws are written to encourage greater investment in the mining sector.

National Defense Stockpile--Gold is not a National Defense Stockpile item; however, the Treasury had stocks of bullion amounting to about 8,146 mt at yearend 1990 (See Figure IIIAiiie-4). Large quantities of gold were also held as commercial and private bullion stocks. Therefore, the availability of gold in times of national emergency appears to be ensured.

Security of Supply--The heightened interest in gold over the past decade has, as in the past, promoted exploration of those remote corners of the Earth were exploration for other less valuable minerals, including minerals of strategic value, could not be justified but where their serendipitous discovery could ultimately contribute to the strategic material needs of society.

Environmental Concerns--The requirements associated with meeting various Federal, State, and local environmental regulations can vary considerably from one mine site to another. At mines utilizing cyanide recovery techniques special precautions, monitoring and leak detection procedures and site design features are employed to avoid contamination of the surrounding environment and to reduce the exposure of wildlife to cyanide laden process streams.

Because of the danger of mercury pollution, the use of mercury amalgamation in domestic gold operations is now virtually nonexistent. Two iron sulfides, pyrite and pyrrhotite, commonly occur in gold deposits and can be a source of stream pollution. Oxidation of these sulfides solubilizes iron and sulfate and lowers pH. Under these lower pH conditions, other metals may be solubilized. Pollution resulting from some placer operations may be reduced or eliminated through the use of properly designed settling ponds. Waste dumps, mill tailings, and excavations are increasingly subject to public scrutiny, and environmental control and site reclamation costs must be taken into account along with other operating factors.

Special Issues Related to Forest Lands--Typical of the issues related to gold mining on Forest lands are those being discussed presently with regard to development of the large New World deposit in Montana. Permit applications to mine this deposit in the Gallatin National Forest are pending. Important issues include cyanide treatment of the ore and

containment and neutralization of mine wastes.

Perhaps the most controversial issue surrounding the New World deposit is its proximity and perceived danger to the greater Yellowstone National Park ecosystem. This ecosystem composed of seven national forests and two national parks is currently being evaluated to determine a suitable land management plan for the area as a whole.

Lead

Lead (Pb) is a soft, heavy metal, the most corrosion resistant of the common metals, and one of the oldest metals used by humans. The major end use of lead is in the manufacture of lead-acid battery systems for Starting-Lighting-Ignition Systems (SLI), Industrial and Motive Applications. About 80% of domestic and over 60% of world consumption of lead is for storage batteries.

SLI batteries are important in the transportation sector, including automotive, marine and aircraft manufacture, as well as in general utility applications such as compressors, generators, drill rigs, etc. Lead is also important in the manufacture of traction batteries. These batteries provide motive power for electric vehicles, including heavy industrial equipment such as forklifts, mine locomotives, etc.

The industrial battery sector consists of uninterrupted power supply systems (UPS) and standby power systems (SBS). UPS are continuously on-line and provide for voltage regulation between external power sources and an appliance. These systems are commonly used to protect electronics, including computers, from damage due to rapid voltage changes. SBS are usually off-line, but available to provide emergency power if the external power source is lost. SBS are found primarily in communication networks. Since 1983, the industrial/traction battery market has doubled in terms of lead usage and promises even greater growth as utility load levelling, especially "customer-side-of-the-meter", and general purpose electric vehicles increase in usage.

One emerging growth area is the consumer battery sector which uses an estimated 5 to 10 kmt of lead per year. These totally sealed, unvented, "gel-cells" compete directly with nickel-cadmium batteries used in toys, lawnmowers, flashlights, power tools, etc. Non-battery oxides for anticorrosion coatings, pigments, and other chemical compounds has become the second major use for lead in recent years, both domestically and worldwide; about 4% in the

U.S. and 14% worldwide. Lead in shot and ammunition also represents about 4% of the U.S. consumption, but only 2% worldwide. Other significant lead end uses include solders, ceramics and glass, color television tubes, electrical cable sheathing and radiation shielding, containers or other packaging, inks and dyes, and cosmetics.

Demand--Figure IIIAiiif-1 shows total apparent lead consumption in the United States from 1963 to 1990. Consumption of lead increased between 1963 and 1979, dropped significantly in 1980, and only recently recovered to early 1970's levels. While U.S. consumption of lead for transportation and electrical uses has increased in recent years, other uses have declined or levelled out. In 1990, consumption of lead in the United States was about 1.3 Mmt, over 1 Mmt of which was in transportation and electrical applications. Also in 1990, the industrial (stationary) and traction (motive) battery sector consumed 172 kmt. Non-battery oxides, pigments, and other chemical compounds, lead use in shot and ammunition, and construction applications accounted for remaining lead consumption.

The United States is largely self-sufficient in its supply of lead. Imports of foreign ore and metal accounted for an average of 15% of total U.S. consumption in the 1980's and slightly less than 10% since 1988. Somewhat higher dependence on these imports existed in the 1960's and 1970's when they accounted for about 25% of U.S. consumption of lead. Recycled lead has played an increasingly more dominant role in meeting U.S. lead requirements since 1963. In 1990, for example, recycled or secondary lead accounted for 67% of U.S consumption. This compared with an average of 52% during the period 1980 to 1989 and an average of 39% from 1963 to 1979. As much as 80% to 90% of lead demand could be supplied by recycling by the year 2040, at least 75% by 2010.

Although domestic demand for lead grew an average of 2% per year from 1980 to 1990, this rate will probably not continue since some end uses will undoubtedly be curtailed, or eliminated entirely, by legislation and/or administrative regulation. One of the current pollution prevention strategies, known as source reduction, will probably reduce the use of lead in nongrowth markets, such as paint, solder, packaging, etc.

Domestic production of lead-containing gasoline additives ceased in mid 1991 and the use of lead in interior paints has been eliminated. With the slowdown in new nuclear reactor construction, where lead is used for shielding and

[45] International Lead and Zinc Study Group (ILZSG). Trends and Consumption of Lead & Zinc, April 1989. p. 31.

radioactive waste handling and storage, and continued international discussions regarding a ban on lead shot in hunting, consumption in these categories could also decline in the future. Use of lead shot for hunting migratory birds already has been banned in the U.S. Some reduction of lead per battery unit can also be anticipated as the technology continues to advance, slowing the rate of growth in this end-use sector.

As a result, U.S. annual growth in lead consumption will probably increase between 0.5% and 1.5% per year in the 1990's, averaging about 1%, as the storage battery sector becomes even more dominant. Figure IIIAiiif-2 shows that a 1% growth rate in lead would lead to an annual lead consumption rate of 2.1 Mmt in 2040. The lower growth rate can be expected if source reduction is applied to the ammunition sector. The higher growth rate could be attained if the use of lead-acid batteries for peak-power, load-leveling applications becomes widely accepted for households and commercial facilities, and/or there is a moderate demand for private general purpose electric vehicles (EVs). The latter two conditions will probably not prevail until the first decade of the next century; hybrid EVs utilizing supplementary internal combustion power are assumed to be the future general use vehicles of choice. These estimates also include allowances for continued use of lead in UPS/SBS battery systems, and some use for "customer-side-of-the-meter" load levelling.

Early in 1991 the "Big Three" domestic automakers announced the formation of the United States Advanced Battery Consortium (USABC) to specifically develop a new generation of batteries for electric vehicles. The Electric Power Research Institute (EPRI) has agreed to cooperate, and on October 25, 1991 the Department of Energy (DOE) agreed to jointly research and fund a four-year $260 million effort to that end. Although lead-acid batteries will certainly be considered, their ultimate acceptance is far from certain, and most of the effort will probably be focused on several promising alternative systems. If a technologic "breakthrough" in another direction is achieved, lead demand beyond 2010 could certainly be severely curtailed.

Geology--The mineralogy of lead ores are relatively simple, with the sulfide galena (PbS) being the major economic mineral. Most lead deposits contain galena associated with sphalerite (ZnS), pyrite (FeS_2), chalcopyrite ($CuFeS_2$), and other base metal sulfides or sulfosalts, some of which are recovered to yield byproducts or coproducts. Galena usually contains variable amounts of silver. Most sphalerite has associated cadmium, in quantities from traces to

2%; and small quantities of germanium, gallium, indium, and thallium.

There are four major types of deposits which have lead as a major constituent: massive sulfide, replacement, vein, and contact metamorphic. The massive sulfide deposits are split into two groups; sedimentary-structural and volcanogenic-stratabound. The sedimentary-structural group includes the Mississippi Valley type (MVT) ore deposits of the Southeast Missouri lead district, which represent the majority of U.S. lead-zinc resources. Other MVT deposits are the Missouri-Oklahoma-Kansas district, the Upper Mississippi Valley district, the Pine Point deposit (Northwest Territory, Canada), the Laisvall deposit in Sweden, and the Central and Eastern Tennessee zinc deposits. The volcanogenic-stratabound group includes those near Bathurst, Kidd Creek, and Sullivan (British Columbia, Canada), Broken Hill and Mount Isa of Australia, and Kuroko in Japan.

Replacement deposits include Cerro de Pasco in Peru, the silver lead district of Central Mexico, Tsumeb in Namibia, Tintic in Utah, and the Leadville and Gilman districts in Colorado. Vein deposits include the Coeur d'Alene district in Idaho, the Silverton area of Colorado, the Santa Barbara, Fresnillo, and Taxco Mines in Mexico, and the German Harz Mountains, Clausthal, and Freiberg deposits. Examples of contact metamorphic deposits include the Kamioka, Obori, Chichibu, and Nakatatsu deposits in Japan.

Mining and Processing Technology--Nearly 90% of the producing lead and zinc mines in Market Economy Countries (MEC) are underground operations. Underground methods used in lead and zinc mining include room-and-pillar, shrinkage, cut and fill, and combinations of these methods. Actual methods depend on the depth and attitude of the orebody as well as characteristics of the mineralized zone and surrounding rock. Open pit mining is employed in Alaska (Red Dog), Australia, Canada, and Mexico.

Over 90% of all producing properties utilize conventional crushing, grinding, and flotation techniques. Flotation generally involves: (1) flotation of lead-copper minerals and the depression of zinc and iron minerals, (2) flotation separation of the lead-copper (if copper occurs in recoverable amounts) concentrate into lead and copper concentrates, (3) activation and flotation on sphalerite (zinc) from iron and other gangue minerals, and (4) flotation of pyrite, if recovery is desired. As many as four concentrates (lead, zinc, low grade lead-zinc, and copper) are produced by flotation. Byproducts (silver, gold, etc.) are usually contained in the lead concentrate.

Conventional blast furnaces are used to smelt about 90% of the lead concentrates. Blast furnace smelting

normally involves: (1) sintering, which fuses an agglomerated mixture of concentrates, fluxes, and various recycled materials to meltable size; this also removes sulfur which is recovered by an acid plant; (2) smelting, which produces impure bullion and slag. If the slag contains appreciable amounts of zinc, it can be processed in a fuming furnace, which produces zinc fume (ZnO), but this is no longer standard practice; (3) the bullion is drossed to remove copper by the addition of elemental sulfur; (4) pyrometallurgical refining, in which any remaining copper and silver is removed by adding sulfur and zinc dust (respectively). Also bismuth, arsenic, antimony, calcium, and magnesium are removed (softening) to produce a 99.95% to 99.99% pure lead. The Imperial smelting furnace may be used to treat complex lead-zinc ores, and electrothermic refining is used in about one-fifth of present day lead refineries.

Resources--Lead resources are found throughout the world. Table IIIAiiif-1 lists the countries with the largest reserves and reserve base of lead. The United States and Australia combined, contain about one-half of the world's reserve base of lead. Canada and the former U.S.S.R. follow with about 13% and 12%, respectively. The total reserve base of lead equals 120 Mmt. In recent years, significant resources (and reserves) of lead have been discovered associated with zinc and/or silver or copper ores in Alaska, Australia, Canada, China, India, Mexico, Pakistan, and the Republic of South Africa. Total identified lead resources of the world are estimated to be as high as 1.5 billion tons.

Table IIIAiiif-2 summarizes lead availability estimates based on production of lead from mines whose primary commodity is lead and from those mines whose primary commodity is zinc. Lead availability from lead mines totals 11.8 Mmt and lead available from zinc mines is 32.3 Mmt for a total lead availability of 44 Mmt. Related costs of production indicate that the United States holds a competitive edge in lead production costs. The United States is one of the low cost producers of lead from zinc mines and is below the world average in production costs for lead from lead mines.

Figure IIIAiiif-3 illustrates the potential availability of lead from producing zinc and lead operations. Almost 24 Mmt (9 Mmt from zinc mines and 15 Mmt from lead mines) of lead is available at under $0.50/lb lead or zinc, depending on the primary commodity of the operation.

World Production--The five major mine producers of lead are Australia, the former Soviet Republics, the United States, Canada and China. World production of lead has been stagnant since 1970, hovering around 3.4 Mmt. Figure

IIIAiiif-4 shows that the lead industry has not changed significantly in terms of primary lead producers' market share since 1960.

National Defense Stockpile--Because of its pervasive worldwide use in the transportation, communications, and electronics industries for electric power storage, lead is classified as a strategic and critical commodity. Figure IIIAiiif-5 shows the National Defense Stockpile (NDS) of lead reached 1.264 Mmt in 1962 before a decision was made to reduce the lead stockpile goals and sell portions considered in excess. In succeeding years the NDS was sold off gradually until it reached 545 kmt at the end of 1974. The NDS has remained unchanged since then, but in 1991 was one of several commodities targeted for elimination under reorganization planning. Industry has maintained stocks of lead in the form of pigs, bars, ore, matte, and base bullion throughout 1960-1990. Industry lead stocks declined from 315 kmt in 1960 to 112 kmt of contained lead in 1990.

Security of Supply--Except for mines in the United States (Missouri), Morocco, and the Republic of South Africa, primary production of lead is closely interrelated, as a result of geologic occurrence, with zinc and silver. All of these metals are recovered from the same ore in most producing countries. A strategic consideration with potentially wide-ranging impact on domestic supply resulting from these coproduct-byproduct relationships arose in 1989. One aspect of the pollution prevention concept, known as source reduction, could entail penalty fees for the use of virgin, i.e. primary, materials in the manufacture of potentially harmful or hazardous products. Elimination of certain lead products from the market place entirely is presently being considered in Congress.

Implementation of this concept could impact the domestic supply of several other metals, owing to their coproduct relationships. A Bureau of mines estimate made in 1990 when the huge Red Dog zinc-lead-silver mine in Alaska came onstream, was that this policy could result in the loss of production of 55% of the zinc and cadmium, and 30% of the silver mined nationally. Also, as byproducts, these same mines were expected to supply all of the bismuth and indium, and about 30% of the germanium mined in the United States.

Environmental Concerns--The primary sources of lead are from underground mining of lead ores and recovery

from scrap material, primarily batteries. In addition to the normal environmental problems associated with underground mines such as surface subsidence, acid mine drainage and erosion and dust from deforested areas, lead mines offer the further problem of airborne lead dust. Benefication plants, and especially smelters, compound the problem of dust containing lead compounds with fumes, which contained high levels of oxidized lead. Recovery of the metal from scrap adds to the problems associated with battery breakage and acid waste streams containing lead compounds. Although sulfide lead ores are not a threat to human health, acid mine drainage from mines and scrap recovery, can react with materials in the environment to produce lead oxide and lead carbonate compounds. These compounds can be toxic if ingested.

Because lead, its oxides, and some other lead compounds are highly toxic, especially to infants and children, whether inhaled or ingested, lead was selected in 1989 by the Environmental Protection Agency (EPA) for a comprehensive, highly publicized, agency-wide, study effort. This effort, known as The Lead Pollution Prevention Program (P4), was completed in 1991, involving several program offices in the EPA. The objective was to develop a comprehensive, cross-media (air-land-water) policy to minimize or eliminate human exposure to lead or its compounds where epidemiological evidence warrants. The policy was framed in the context of pollution prevention rather than waste minimization, but still specified some command-and-control techniques to achieve parts of the objective, including more timely, predictable, and realistic enforcement practices. The new lead policy, when finally determined, could serve as a model for tackling other major health risk problem areas as the Nation moves toward a "uniform environmental code" during the rest of this century.

Special Issues Related to Forest Lands--The Mark Twain National Forest in Missouri is the most productive source of lead in the United States. Recent attempts, however, to explore and develop new reserves have been delayed by environmental concerns.

In the Eleven Point District, a request to drill 10 or more holes to better define a newly-discovered zone of lead mineralization has been delayed by the appeals process. The major issue is whether or not these exploration holes can be drilled without contaminating two major aquifers in the area. Complicating the issue further is an attempt by the National Park Service to have these aquifers designated by the Environmental Protection Agency (EPA) as sole-source aquifers. If

this designation is achieved, the EPA will have jurisdiction over matters pertaining to the aquifers in a highly mineralized area of about one million acres.

Molybdenum

Molybdenum (Mo) is a refractory metallic element used principally as an alloying agent in steels, cast irons, and superalloys to enhance hardenability, strength, toughness, and wear and corrosion resistance. Primarily added in the form of molybdic oxide or ferromolybdenum, it is frequently used in combination with chromium, columbium, manganese, nickel, tungsten, or other alloy metals to achieve desired metallurgical properties. The versatility of molybdenum has assured it a significant role in contemporary technology and industry, which increasingly require materials that are serviceable under higher stresses, greater temperature ranges, and more corrosive environments. Moreover, molybdenum finds significant usage in numerous chemical applications, including catalysts, lubricants, and pigments. The variety of uses for molybdenum materials, few of which can accept substitutes, has resulted in a demand that is expected to grow at a greater rate than most other ferrous metals.

Demand--Molybdenum consumption follows the production of iron and steel products. With the decline in the production of these products from domestic factories, the apparent consumption of molybdenum has also declined from peak levels in the late 1970's. Figure IIIAiiig-1 depicts the recent trend in domestic molybdenum consumption. Domestic production, which historically has been substantially greater than domestic consumption, fell off from its peak production year in 1980 until 1983 when there was actually a production shortfall. Demand was met in that year by drawing down industry stocks. Consumption has been erratic in recent years. In 1990 apparent consumption reached 21 kmt.

U.S. molybdenum demand is expected to continue to be dependent on the growth of iron and steel production. Molybdenum demand in other areas appears to follow the general world industrial growth. Figure IIIAiiig-2 depicts U.S. molybdenum consumption forecasts. The molybdenum commodity specialist estimated that, given the potential domestic construction and industry needs, U.S. molybdenum consumption will grow at an average annual rate of 1% per year from 1990 to 2040.

Geology--Molybdenum deposits are classified into five genetic types: (1) primary porphyry or disseminated deposits, including stockworks and breccia pipes in which metallic sulfides are dispersed through relatively large volumes of altered and fractured rocks; (2) contact metamorphic zones and tactite bodies of silicated limestone adjacent to intrusive genetic rocks; (3) quartz veins; (4) pegmatite and aplite dikes and; (5) bedded deposits in sedimentary rocks.

The first three genetic types are determined to be hydrothermal in origin. As such, nearly all resources in the world fall under these types. The remaining two types currently do not possess any economically important deposits. Molybdenum from these two types is recovered only as a byproduct and then only when it interferes in the metallurgical recovery of the primary product.

Primary porphyry deposits, the major source of molybdenite, occur as small disseminated grains in veins and veinlets of hydrothermally altered igneous rocks. The mineralization normally is associated with an intrusion along fault intersections. Generally, the intrusive rocks are siliceous with composition ranging from granodiorite to granite. The mineral concentration in the primary deposits ranges from 0.1% to 0.5% MoS_2.

Copper-molybdenum porphyry deposits are somewhat similar in origin to that of primary molybdenum porphyry deposits. The deposits are related to silicic intrusions and hydrothermal alteration. Molybdenite concentration is much lower, ranging from 0.01% to 0.015% MoS_2.

In contact-metamorphic deposits and tactite deposits, molybdenite is widely distributed along the contact between granitic intrusive and lime-rich sedimentary rocks. In many places, the size, shape, and occurrence of the ore bodies indicate that the mineralization was controlled by pre-ore fracturing of the lime-rich host rocks. The deposits are generally small, but contain relatively high molybdenite concentrations, up to 0.60% MoS_2. Molybdenite also occurs in fissure or quartz deposits. The vein filling is mainly quartz and molybdenite and minor amounts of pyrite, chalcopyrite, and chlorite and varies in size from a fraction of an inch to several feet. The mineral concentration also varies widely, and most of the molybdenite is fairly fine grained and appears to be concentrated along the vein walls or joints and seams.

Pegmatite and aplite dike deposits are igneous rocks that were formed by magmatic fluid filling dikes with rock composition similar to that of the associated pluton. Molybdenite generally occurs in coarse crystalline structure, forming large rosettes and aggregates of flakes, which are valued as mineral specimen rather than as a source of molybdenum.

Mineralization normally occurs in small pods that have no connection to other pods. Therefore mining is limited to single pods.

Molybdenite is also found in bedded sedimentary rocks like coal and shale, though the concentrations are too low to be of economic significance. In some lignitic sandstone deposits, the mineral approaches economic concentrations. Some molybdenite minerals are also associated with bedded uranium. In such deposits, when the mineral reaches a high level of concentration, it became necessary to separate the molybdenite, as it interferes with uranium recovery.

Mining and Processing Technology--Ore deposits are mined by either underground or open pit methods. The selection of a mining method for a given deposit is more or less controlled by the grade, size, shape, and attitude of the ore body. Normally, the ideal choice is the one that gives safe working conditions and yields the greatest economic profit. Since primary molybdenum deposits occur as low-grade, high tonnage porphyry deposits, low-cost underground block-caving and open-pit operations are the most commonly used methods to extract the ore.

To separate the molybdenite from the gangue minerals, the ore is crushed and ground to a size where the mineral is liberated. The size requirement is controlled by the ore characteristics, economics, and available processing technology. Molybdenite is a relatively easily floatable mineral, so concentration always involves crushing and grinding to release the mineral, followed by flotation. Crushing of molybdenite ore, as practiced by primary molybdenum producers, consists of primary, secondary, and tertiary crushing systems. Semi-autogenous crushing is practiced in some mines where run-of-mine ore is crushed through the primary stage only to take advantage of the grinding effect of the rock size.

Resources--At present, all primary molybdenum mines and known deposits in Market Economy Countries are situated in continental North America. Significant reserves of molybdenum also exist as by-products of South America, Iran, and Chinese mines. Table IIIAiiig-1 lists world molybdenum reserves and reserve base figures for primary producing countries as of 1990. The reserve base totals 11.8 Mmt of contained molybdenum, of which 5.5 Mmt may be considered reserves. The United States (45%), Chile (21%), and China (10%) have the largest portions of the world's estimated molybdenum reserve base.

An availability study of molybdenum in Market Economy Countries (MEC), published by the Bureau in 1985, estimated that there were 9.6 billion pounds of molybdenum available from primary deposits, as shown in Figure IIIAiiig-3. This study was based on a DCFROR of 15%. Table IIIAiiig-2 shows the breakdown of costs to produce molybdenum. About a quarter of the resource is available at under $4.00 per pound, measured in 1983 dollars.

World Production--Molybdenum production is concentrated in a few countries of the world. World mine output was an estimated 112 kmt in 1990, of which the United States, Canada, Chile, and the former U.S.S.R. provided 90%. These four countries, led by the United States, have an annual production capacity of 137 kmt and are expected to continue as the principal producers of molybdenum in the foreseeable future.

Figure IIIAiiig-4 shows the composition and level of world molybdenum production since 1960. The United States has been, with the exception of 1983, the dominant producer of molybdenum in the world. In 1990, production from the United States comprised 55% of the world production, followed by Chile (12%), Canada (12%), and the former U.S.S.R. (10%).

National Defense Stockpile--Molybdenum materials were maintained in the U.S. Government Stockpile until 1963, when the government began selling portions of the stockpile as a result of adequate industry stocks. By 1976 the government stockpile was entirely liquidated, as shown in Figure IIIAiiig-5. Except for periods in the early 1970's and 1980's industry stocks have been fairly consistent and adequate. The industry has averaged around 20,000 mt over the past eight years.

Security of Supply--Reserves of molybdenum are abundant in North America, with the United States having 2,720 kmt, Canada 450 kmt, and Mexico 90 kmt. Additionally, these three countries have a total annual production capacity of 978 kmt, mitigating the threat of supply interruption during a period of mobilization. Other significant reserves are available from South America, mostly from Chile, where molybdenum reserves total 1,270 kmt, and annual production capacity is 250 kmt.

Environmental Concerns--Compared to other industrial metals, molybdenum exhibits very low, negligible toxicity. No significant toxic effects in human beings have been identified in mining or processing of molybdenum materials. As an environmental trace element, molybdenum is an essential micronutrient. Deficiencies of molybdenum can affect the normal growth and development of plants and animal species, including humans.

The production of molybdenum requires the removal of large volumes of material. Both underground and open pit operations can create large land disturbances. In addition to the subsidence associated with underground mining, open pit operations remove natural ground cover and thus introduce erosion and dust into the environment. Vast volumes of material containing little or no molybdenum must be removed and stacked around the perimeter of the operation in order to mine the ore. This creates large volumes of waste material which covers natural vegetation, generates dust and contains leachable heavy metals. Because most molybdenum mines are found in arid environments, the benefication of the ores consumes large volumes of precious water and produces vast areas of tailings. Because tailings are only a finely ground version of the waste material, they also cover natural vegetation, become vast areas of dust generation and contain leachable traces of heavy metals. The smelting of concentrates from benefication plants produces fugitive sulfur dioxide emissions, slag heaps rich in heavy metals and a variety of waste streams.

The industry has met environmental concerns through backfilling operations, introducing ground cover to waste and tailings piles, increased recycling of water, increased capture and treatment of sulfur emissions and containment and treatment of waste streams.

Special Issues Related to Forest Lands--One of the largest molybdenum deposits in the world occurs in the Tongass National Forest of Alaska. This deposit, known as Quartz Hill, lies within the Misty Fiords National Monument and is subject to stringent constraints for development.

The principal issue concerning development of the Quartz Hill deposit is tailings disposal. The mining company wants to pump the concentrator tailings onto the floor of the Wilson Arm fiord. This plan has been accepted by the Forest Service but is currently unacceptable to the Environmental Protection Agency (EPA). The EPA and other environmental

interests object because they believe that the marine environment will be severely impacted.

Phosphate Rock

Phosphorus, nitrogen, and potassium are the three primary nutrients necessary for plant growth. When these elements are either lacking or depleted from the soil, their addition is necessary to maintain high agricultural yields. Phosphate rock is the only significant commercial source of the element phosphorus and is of vital importance to an expanding agricultural sector worldwide. The use of phosphate in fertilizers accounts for over 90% of annual phosphate consumption worldwide. There is no substitute for phosphate in agriculture. Phosphate is also used in animal feeds, in detergents, and in numerous industrial applications.

After beneficiation, phosphate rock ranges from 26 to 39 pct P_2O_5 (phosphorus pentoxide). Phosphate rock can be converted to phosphoric acid, converted to elemental phosphorus in an electric furnace, or applied directly to acidic soils. Most of the phosphate rock produced in the world is used to manufacture wet-process phosphoric acid.

Demand--Phosphate rock consumption is driven by demand for food, primarily in the form of grain. Figure IIIAiiih-1, U.S. phosphate rock (PR) production/apparent consumption, shows the historical record from 1964 through 1990. With few setbacks, the demand for phosphate rock in the United States steadily climbed from about 17 Mmt in 1964 to 44 Mmt in 1990. The United States is self-sufficient in production of phosphate rock and has been a major, though declining exporter of phosphate rock into world markets. The U.S. share of phosphate traded in world markets has declined in relative terms, in part, because of the growth in phosphate exports by Morocco.

In recent years, U.S. phosphate fertilizer exports have played a major role in increasing the demand for U.S. phosphate rock. U.S. phosphate rock demand consists of two components, i.e., rock converted into phosphate fertilizers

[46]Following industry practice, the term "phosphate rock" is defined as the mined, or mined and beneficiated, product of phosphate ore rather than the in situ material.

that are either (1) consumed by farmers domestically or (2) exported. In the latter case the rock was "consumed" domestically to make fertilizers that were then exported. However, this situation is expected to change due to the depletion and exhaustion of some Florida phosphate deposits after the year 2005. Florida phosphate rock operations currently supply phosphoric acid plants in central and coastal Florida, acid plants along the Golf coast, and a component of world phosphate rock trade. Reduced production capability in Florida will be faced in different ways by operating phosphoric acid companies. Those on, or near, tidewater may opt to import phosphate rock to make up for lower rock availability from Florida; some acid plants may close; improved technology may allow some companies to increase Florida capacity above that which is projected. Exports of phosphate rock from Florida will probably cease by the turn of the century. A combination of reduced supply availability, increasing imports, and some phosphoric acid plant closures will likely reduce U.S. phosphate rock consumption from 40 Mmt to 30-35 Mmt between 2005 and 2015, which will adversely affect phosphate-based fertilizer exports. The remaining component of U.S. demand for phosphate rock is expected to grow at an annual 0.5 percent rate throughout the forecast period (see Figure IIIAiiih-2).

World phosphate rock demand was relatively depressed in recent years because grain stocks in North America and West Europe were high, causing a reduction in grain prices and compulsory set-aside of land. The sharp reduction in phosphate demand in a number of East European countries in 1990 after the political and economic changes also contributed to the reduction.

Short-term (1990-2005) world demand for phosphate rock has been estimated for the Bureau by the WEFA Group at a growth rate averaging 0.97%, ranging from a low in 1991 of 0.3% to a high in the years 1996-2000 of 1.3%. The WEFA Group is projecting a slower rate of growth in world fertilizer consumption in the 1990s then was experienced in the 1980s. Fertilizer prices are expected to be weak (actually continuing to decline when adjusted for inflation) and the associated costs of production are expected to rise causing an increase in prices, decreasing crop production profitability and slowing the rate of growth in fertilizer application rates. Growing environmental concerns, particularly in North America and Western Europe, will also cause a reduction in application rates and reduce acreage fertilized.

[47] The WEFA Group, World Demand for Fertilizer Nutrients for agriculture, Report prepared for the U.S. Bureau of Mines, February, 1992, 53pp.

Geology--The element phosphorus is widely abundant in the Earth's crust, comprising approximately 0.11 pct. Phosphate (phosphorus pentoxide P_2O_5) concentrations exist throughout the world in both igneous and sedimentary rocks, primarily in the form of the mineral apatite. In igneous rocks, it is generally as fluorapatite, and in sedimentary rocks, generally as hydroxy fluorapatite, or as carboxyapatite.

The majority of the phosphate resources throughout the world are classified as sedimentary marine phosphorite deposits. The two most significant types are deposits are those formed in areas of upwelling water and those formed in warm climates, particularly along eastern coasts. The Cretaceous and Eocene deposits of western and northern Africa and the Middle East as well as the Permian Phosphoria Formation of the Western United States are the best examples of deposits formed as a result of upwelling waters. These deposits were formed by chemical and biological precipitation of phosphate in areas of upwelling, phosphate-rich marine waters. The phosphate ore typically occurs in thin, marine sediment sequences in these deposits, and the phosphate itself is typically carbonaceous, consisting of pellets and nodules. The Miocene deposits along the southeastern coast of the United States are the best examples of deposits formed in warm climates. These deposits are economically mineable if they have been reworked by submarine currents and/or subjected to weathering (as in the Southeast United States). The phosphate ore typically consists of loose, poorly consolidated phosphatic sands, and soft calcareous clays, marls, etc.

In igneous rocks, apatite usually occurs as intrusive masses or sheets, as hydrothermal veins or disseminated replacements, as marginal differentiations, or as pegmatites. Intrusive masses are the most common occurrence of igneous apatite, usually associated with alkaline igneous rocks including carbonatite, ijolite, nepheline synenite, and pyroxenite. Examples of these types of deposits are in the Kola Peninsula in Russia, the Palabora complex in the Republic of South Africa, and the carbonatites of southern Brazil.

Another type of phosphate deposit is the island phosphate deposit, which is formed through the large accumulation of guano from sea birds. The composition of these deposits varies with the degree of leaching by surface waters. Decomposed guano is primarily calcium phosphates. The deposits on Nauru and Christmas Islands in the Pacific and Indian Oceans, respectively, are the best examples of guano deposits.

Mining and Processing Technology--Over 90% of world phosphate rock production is recovered by surface mining methods, the remainder is recovered by underground mining techniques. The two major surface mining methods used in the phosphate industry are strip mining and open pit mining. A third method, dredging, is used in special situations. Strip mining accounts for 90% of U.S. and about 60% of total world phosphate rock production. It is the method predominantly used because of the tabular, bedded, sedimentary nature of most phosphate deposits. Most deposits in the Southeastern United States and North Africa use this method. Open pit mining is typically employed for resources of hard igneous carbonatite rock. Dredging is used in special hydrologic situations for which the overburden and phosphate horizon are unconsolidated clay and sand.

The relatively low unit value of phosphate rock makes underground mining methods generally unprofitable. However, steeply dipping phosphate beds, or high stripping ratios sometimes make the use of underground mining techniques preferable. In such cases, highly mechanized room-and-pillar, longwall caving, and overhand-stoping methods have been used successfully. The majority of producing underground phosphate mines are located in Morocco and Tunisia.

In almost all cases the run-of-mine phosphate material has to be beneficiated. The basic beneficiation methods employed in the phosphate industry are sizing, washing, flotation, and calcining. A phosphate beneficiation plant may use one or more of these methods to produce a marketable product.

Most of the phosphate rock produced in the United States and the rest of the world is used to manufacture fertilizer products (phosphoric acids) to be used by the agricultural industry. The various fertilizer products produced from phosphate rock are wet-process phosphoric acids, normal superphosphates, triple superphosphates, monoammonium phosphates, diammonium phosphates, and direct application of ground phosphate rock (phosphate rock that is applied directly to acidic soils in many regions of the world).

Resources--Table IIIAiiih-1 lists world phosphate rock reserves and reserve base. According to the data shown, Morocco and Western Sahara, and the United States possess about three-fourths of the reserve base of phosphate rock.

Table IIIAiiih-2 lists the potential availability of phosphate rock resources from 201 mines and deposits in 28 Market Economy Countries (MECs). The MEC mines and deposits contain an estimated 34.5 billion mt of recoverable phosphate rock at the demonstrated resource level. North Africa contains the greatest share of this resource, 22.0 billion mt, or 64%, most of which is located in Morocco. The United States contains 5.8 billion mt, or 17%. Seventeen mines and deposits in the former U.S.S.R. and in P.R. China were not included on the table or on the availability curve. The demonstrated phosphate rock resource from those countries is approximately 1.5 billion mt.

Figure IIIAiiih-3 shows the potential availability of phosphate rock from the MECs. The curve represents those resources which can be recovered at a total cost of $100/mt or less, 33.4 billion mt from a total resource of 34.5 billion mt. The figure shows that 80% of Phosphate rock resources are available at under $40/mt phosphate rock.

World Production--World production of phosphate rock for 1990 was 153 Mmt of rock, with an average P_2O_5 grade of 30.8 percent (Figure IIIAiiih-4). Three countries, the United States the former U.S.S.R., and Morocco, account for about two-thirds of production. China and Tunisia are other large producers. In 1964 the United States produced 23 Mmt of phosphate rock and accounted for over 40% of world production. In 1990, the United States was still a dominant factor in world production of phosphate rock, but increases in production in other countries reduced its market share. U.S. production in 1990 grew to 45 Mmt or 30 % of total world production of 153 Mmt.

In international trade of phosphate rock, the United States is second to Morocco as the leading exporter. Morocco and the United States account for just over one-half of the 1990 worldwide exports. Exports from the United States and Morocco count for about 24% of world production.

National Defense Stockpile--Phosphate rock is not included in the National Defense Stockpile. Frequently the industry maintains over 10,000 tons of phosphate rock in wet-rock storage piles in the United States. These stocks, illustrated historically in Figure IIIAiiih-5, are available to meet any unforseen demand.

Security of Supply--Phosphate rock is traded worldwide. The large reserves in North Carolina and Florida assure a secure domestic supply. The estimated U.S. phosphate rock reserve, recoverable at less than $40 per ton f.o.b.

mine, exceeds 1.2 billion mt. The reserve base, recoverable at a cost of less than $100 per ton f.o.b. mine, exceeds 4.4 billion tons of recoverable phosphate rock. The United States in 1990 exported 71% of the phosphate rock mined as phosphate rock, phosphate fertilizer, or phosphate chemicals.

Environmental Concerns--Open-pit phosphate rock mines disturb the land and beneficiating phosphate matrix consumes large volumes of aquifer water, produces colloidal clay wastes from washing operations, and sand tailings from floating a concentrate. Converting phosphate rock into phosphoric acid produces a phosphogypsum by-product that must be stored in open stacks. Concern exists over the possibility of phosphogypsum stacks polluting surficial aquifers, and releasing radionuclides into the atmosphere.

All of the electric furnaces in Tennessee have been closed. Operating phosphate electric furnaces in Idaho and Montana have installed emission controls to minimize losses of phosphorus and fugitive dust to the atmosphere.

Special Issues Related to Forest Lands--Phosphate rock deposits have been discovered in the Los Padres National Forest, California, the Osceola National Forest, Florida, and the Caribou National Forest, Idaho. Lease applicants were denied preference right leases in the Los Padres and Osceola Forests. The 98th Congress of the United States directed that the Department of the Interior not issue phosphate leases in the Osceola National Forest, Florida. The taking of the rights of the lease applicants was referred to the United States Claims Court. The Court is considering this issue but has not made a judgement.

Platinum-Group Metals

The platinum-group metals (PGM) comprise six closely related metals: platinum, palladium, rhodium, ruthenium, iridium, and osmium, which commonly occur together in nature and are among the scarcest of the metallic elements. Along with gold and silver, they are known as precious or noble metals. They occur as native alloys in placer deposits, or more commonly, in lode deposits associated with nickel and copper. Nearly all of the world's supply of these metals are extracted from lode deposits in four countries--the Republic of South Africa, the former U.S.S.R., Canada, and

the United States. The Republic of South Africa is the only country that produces all six PGM in substantial quantities.

PGM have become critical to industry because of their extraordinary physical and chemical properties--the most important of which is their catalytic activity. Since the mid-1970s, automobile manufacturers have used catalytic converters (autocatalysts) containing platinum and palladium, and, in more recent years, three-way catalysts containing rhodium in combination with platinum and/or palladium to reduce emissions of the three major automobile pollutants--carbon monoxide, hydrocarbons, and nitrous oxides. Similarly, the chemical and petroleum-refining industries have relied on PGM catalysts to produce a wide variety of chemicals and petroleum products.

Demand--The U.S. reported consumption was 77 mt out of a total world consumption of 238 mt of PGM in 1990. The United States was the second largest consumer of PGM after Japan.

U.S. apparent consumption for PGM has roughly tripled over the past 30 years, as shown in Figure IIIAiiii-1. While electrical and electronic applications for PGM are still important, the use of PGM in autocatalysts has grown to become the single largest application for PGM today, both for the United States and the world. Worldwide environmental concern is the driving force behind PGM demand in the autocatalyst industry.

There has been a shift in the usage of palladium from that of low voltage electrical contacts in telephone equipment to that of conductive material in multi-layer ceramic capacitors and hybrid integrated circuits. The explosive growth in consumer electronics has contributed to sustaining demand for palladium in the electronics industry.

In the future, usage of PGM in autocatalysts should continue to expand as more countries adopt legislation requiring controls on automobile emissions. While U.S. automobile sales in recent years have shrunk, the amount of PGM used in each autocatalyst has increased because of increasingly more stringent emission regulations.

A promising and potentially large new application for platinum is in fuel cells. Three companies started commercial production of fuel cells in 1990, opening the possibility for more use of platinum in fuel cells. Fuel cells produce electricity by combining hydrogen and oxygen in an electrochemical reaction, with platinum acting as a catalyst. Fuel cells can be used in utility power plants, as on-site generators, or in electrically powered vehicles. A discussion of the

[48] Johnson Matthey PLC. Platinum 1991. 64pp.

future of fuel cells was presented in a 1991 platinum industry report.

U.S. demand for PGM is expected to reach 107 metric tons by the year 2000, with an average annual growth rate of 3.3%. In the period 2000-2040, the demand for PGM was forecast to grow at a lower average annual rate of 2.8%. Figure IIIAiiii-2 shows the historical and forecast demand for PGM.

Geology--PGM deposits are associated with magmatic intrusions of mafic and ultramafic rocks. They also occur to a lesser extent as placer deposits. Layered deposits associated with stratiform complexes are the only ones mined principally for the PGM, with nickel and copper and sometimes gold and cobalt produced as byproducts. These are found in the Bushveld Complex, Republic of South Africa, and the Stillwater Complex, United States.

In other PGM deposits, such as those found in the Sudbury Complex, Canada, and Noril'sk, former U.S.S.R., the PGM are produced as byproducts of nickel and copper mining.

Mining and Processing Technology--Platinum ores generally occur in thin layers called reefs. After the reefs are drilled and blasted, the platinum ore is brought to the surface and crushed and treated by froth flotation. The concentrates are dried, sometimes roasted, and then fused in a smelter furnace, producing a sulfide matte containing the PGM. The matte is treated in a refinery using solvent-extraction techniques to separate and purify the six PGM.

Resources--World resources of PGM are estimated at 100,000 mt. Reserves and reserve base, by country, is shown in Table IIIAiiii-1. South Africa holds 90% of the reserves with the rest located in the former U.S.S.R., the United States, and Canada.

The Bureau of Mines' Mineral Availability Field Office performed a discounted flow rate-of-return (DCFROR) analysis to determine long-run prices of platinum, palladium, and rhodium. The properties evaluated were in the Republic of South Africa, the United States, Canada, and Zimbabwe. Table IIIAiiii-2 summarizes the availability distribution of recoverable platinum, palladium and rhodium at a 0% DCFROR. The 0% DCFROR production cost covers all costs and capital recovery with a 0% rate-of-return on invested capital. The total production costs ranged from $350 per troy

[49] Johnson Matthey PLC. Platinum 1991. 64pp.

ounce to over $650 per troy ounce of platinum. Figure IIIAiiii-3 shows that most platinum is recoverable at a price of $450 per troy ounce; figure IIIAiiii-4 shows that most palladium is recoverable at a price of $120 per troy ounce; and figure IIIAiiii-5 shows that most rhodium is recoverable at a price of $1,100 per troy ounce.

World Production--Most PGM, over 90% of the world's production, are produced in only two countries--the Republic of South Africa and the former U.S.S.R., as shown in Figure IIIAiiii-6. In addition, Canada, the United States, and a host of other countries are smaller producers that make up the balance of PGM production. Production in the former U.S.S.R. is primarily palladium, with smaller quantities of platinum and rhodium, while South African production is primarily platinum, with smaller quantities of all the other PGM. In the former U.S.S.R. PGM is produced as a byproduct of copper-nickel mines north of the Arctic circle in Siberia, while most South African production is a byproduct of platinum ores mined from the Merensky and UG-2 reefs in the Bushveld Complex.

In the past, U.S.S.R. production has been roughly equivalent to South African production. In the future, South African production is expected to rise as a result of announced substantial mine expansions to meet world autocatalyst demand, while production in the former U.S.S.R. is expected to remain constant. Johnson Matthey noted that one of the constraints on expansion of Soviet production is the already severe pollution caused by the emission of an estimated 3.5 Mmt of sulfur dioxide from the nickel-copper smelters each year.

National Defense Stockpile--The status of the National Defense Stockpile for five separate PGM materials is shown in Table IIIAiiii-3. Rhodium and ruthenium are the most likely metals to be purchased in the future because there are goals established but no inventories of these metals.

Over the past 30 years, U.S. Government sales of PGM were substantial in only one year, 1966, when 10 mt were sold. Figure IIIAiiii-7 shows that U.S. Government acquisitions totaled 20 mt between 1961 and 1970. In recent years, however, acquisitions have been relatively minor. The National Defense Stockpile is currently at 65 mt. Industry stocks have fluctuated from 20 to 40 mt over the period and are currently at 30 mt.

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[50] Johnson Matthey PLC. Platinum 1991. 64pp.

Security of Supply--Because PGM are considered strategic metals and most PGM are imported from the Republic of South Africa and the former U.S.S.R., security of supply has been a source of constant concern for U.S. policy makers for many years. Despite political turmoil in both countries, very few disruptions in supply have actually occurred. The United States has limited supplies of PGM ore available from the Stillwater Mine in Montana that could be expanded in case the need arose. In addition, the owners of the Stillwater Mine (Chevron Corp. and Manville Corp.) operate a PGM smelter in Columbus, Montana, 40 miles northeast of the Stillwater Mine.

Environmental Concerns--Although the Stillwater Mine is adjacent to the Beartooth-Absaroka Wilderness area, precautions have been taken to protect the ecology of the area. The Stillwater Mine near Nye, Montana, has a tailings pond impoundment lined with 100 mil (1/10 inch) high density polyethylene to prevent groundwater seepage. The company uses clarifiers for primary treatment that extracts particulates and metals from the tailings pond water. Through the use of land application sprinklers and percolation ponds, no water is directly discharged to the Stillwater River. The Stillwater Mining Company has worked with the U.S. Fish and Wildlife Service in providing assistance in evaluating the Big Horn sheep population in the area. The PGM smelter located in Columbus, Montana, emitted 3.2 mt per year of sulfur dioxide 1991.

Special Issues Related to Forest Lands--The only platinum mine in the Western Hemisphere occurs in the Custer National Forest of Montana. The Stillwater Mine produces small, but significant, quantities of the critical metals, palladium and platinum.

A major issue concerning proposed expansion of the platinum mine and development of new mines in the stillwater Complex is potential degradation of surface waters. State law does not allow any increase of regulated wastes or contaminates to be discharged into surface drainages, even though the increased level of contaminant may be within acceptable prescribed limits. Other issues include tailings impoundment and reclamation and waste rock disposal.

Zinc

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[51]Personal communication January 16, 1992, with Bruce Gilbert, Stillwater Mining Company, Nye, Montana.

[52]Personal communication January 13, 1992, with Greg Roset, Stillwater Mining Company, Columbus, Montana.

Zinc (Zn) is the world's fourth most widely used metal after iron, aluminum, and copper. It is ubiquitous in the modern economy but its presence is often not obvious to the public because zinc tends to lose its identity in end products. Zinc-containing products are extensively used by industry, government, the general public and the military for construction, transportation, electrical, machinery and a myriad of other purposes.

About three-fourths of zinc used is consumed as metal, mainly as a coating (galvanizing) to protect iron and steel from corrosion, as alloying metal to make brass, as zinc-based diecasting alloy, and as rolled zinc. The remaining one-fourth is consumed as zinc compounds mainly by the rubber, chemical, paint and agricultural industries as reactants, pigments, phosphors, catalysts, wood preservatives, and nutrients. Zinc is a required element for most plant and animal life forms and is a common constituent in vitamin supplements.

Substitution for zinc depends on price and availability of substitutes as well as their technical suitability. Virtually all areas of zinc use have been susceptible to some form of reduced zinc consumption either through substitution or technical innovation. Zinc, aluminum, magnesium, and plastics are competitive materials in diecasting where weight, temperature tolerances, and surface finish are important factors. The use of molded plastics for automobile body parts in particular, has supplanted galvanized steel sheet uses.

Although emphasis on corrosion protection has led to increased zinc consumption in the galvanizing sector, former all-zinc coatings are increasingly being replaced by zinc alloy coatings containing less zinc than before, by thinner coatings (reduced coating weights), or by alloys such as aluminum-based Galvalume. Aluminum alloys, stainless steel, cast iron, and plastics have replaced significant tonnages of brass in building and marine hardware, plumbing goods, and decorative uses. Aluminum and magnesium replace zinc as reducing agents in chemical reactions and titanium and zirconium compounds are highly competitive in pigment, ceramic, and enamel applications. Zinc compounds formerly were consumed in large amounts in the paint, photocopy, and synthetic fiber industries, but consumption in these industries has been severely impacted by substitution or technological change.

Demand--The United States has been the leading world consumer of zinc since the early 1900's and, historically,

is estimated to have consumed about one-fourth of total world output. Figure IIIAiiij-1 shows U.S. zinc consumption reached a record high of almost 1.5 Mmt in 1973 but averaged only about 1.0 Mmt thereafter, mainly owing to a reduced demand by domestic manufacturers due to a large influx of imported finished and semi-finished goods and to retrenchment of the domestic steel and automobile industries. During the 1980's domestic sources of zinc supplied about a third of apparent consumption, and, since the 1940's, has never produced enough zinc to meet domestic demand. In recent years the United States imported about two-thirds of its refined zinc requirements.

U.S. demand for zinc was forecast to rise approximately 1.2% annually, increasing from about 1.0 Mmt in 1990 to 1.2 Mmt by the year 2000 and to 1.8 Mmt by 2040 (see Figure IIIAiiij-2). As no new major zinc-consuming uses are on the horizon, traditional zinc uses in meeting the needs of a growing and more affluent population is expected to be the driving force for increased zinc usage, at least for the next few decades.

World per capita consumption of zinc metal has tended to climb steadily since 1800 and in the 1980's decade, averaged about 1.35 kilograms (see Table IIIAiiij-1). Based on U.S. Census forecasts of world population and assuming the average global per capita rate is unchanged from that of the 1980's decade, the future world demand levels in 2000 and 2040 would be about 8.5 Mmt and 13.4 Mmt, respectively. Substantially higher future demand is possible if world per capita consumption continued to rise and approach that of the U.S., about 4 kg per person in 1990.

Geology--Zinc is the twenty-third most abundant element, averaging about 80 parts per million in the earth's crust. A cubic mile of crust, surprisingly, contains about 1 million metric tons of zinc. Exploitable zinc deposits are found in many diverse geological environments but mainly occur as massive sulfides of volcanogenic origin stratabound in volcanic and sedimentary rocks; as stratabound veins, replacements, and breccia fillings in carbonate rocks; as vein deposits associated with base metals, silver and gold; as metamorphic deposits; and as near-surface oxidized zinc deposits. U.S. production has come largely from deposits in carbonate rocks and veins but, beginning in 1990, massive sulfide ore from the Red Dog Mine in Alaska contributed two-fifths of U.S. output and in the future is expected to account for about one-half.

Sphalerite, zinc sulfide, is and has been the principal zinc ore mineral mined worldwide. In the United States oxidized zinc minerals in metamorphic rocks and in near-surface deposits have accounted for about 15% of zinc mine output; sphalerite has accounted for virtually all the rest.

Mining and Processing Technology--Nearly all zinc-producing mines are underground operations, although a few of the world's largest zinc-producing mines, including Red Dog, have been or currently are open pit operations. Generally underground ore bodies are reached by vertical or inclined shafts, whereas near-surface ore bodies are exposed by stripping off the overlying soils and rocks. Underground mining typically involves room and pillar, shrinkage, or cut and fill methods, or some combination of these methods. Actual methods employed depend on the depth and attitude of the ore body as well as the characteristics of the mineralized zone and surrounding rocks. The cycle of operations for both surface and underground mining consists of drilling, blasting, and removing broken rock.

Most zinc ores are treated in a mill to separate (and concentrate) the valuable minerals from the unwanted minerals or gangue. The process typically involves crushing and grinding followed by froth flotation, a process involving a number of steps whereby specific minerals in water can be surface conditioned by reagents to rise via attachment to air bubbles, hence the term flotation. The process generally involves: (1) flotation of copper and lead sulfides and depression of zinc and gangue minerals; (2) flotation separation of copper and lead, if required into two concentrates; and (3) activation and flotation of sphalerite with continued depression of the gangue minerals. The zinc concentrates are dewatered and shipped to smelters for reduction to zinc metal. The mill tailings (gangue) are generally discharged into surface tailings ponds, although at some operations, the tailings are used as mine fill, construction material, or agricultural lime.

Smelting. Reduction of the concentrates to zinc is accomplished by electrolytic deposition from a sulfate solution or by distillation in retorts or furnaces. For either method, the zinc concentrate is roasted to eliminate most of the sulfur and produce impure zinc oxide known as roasted concentrate or calcine. At electrolytic zinc plants, which comprise about four-fifths of world primary metal capacity, the calcine is leached with dilute sulfuric acid to form a zinc sulfate solution. The solution is then purified and piped to electrolytic cells, where the zinc is electrodeposited on aluminum cathodes. The cathodes are lifted from the tanks at intervals and stripped of the zinc, which is melted and cast into slabs. In retort methods, calcine or sinter together with coal or coke as a reducing agent yield at high temperatures zinc vapor and carbon monoxide which pass into a condensation zone or splash-type condenser where the zinc is collected as liquid metal ready for casting into slab form.

Resources--Table IIIAiiij-2 lists world zinc reserves and reserve base. The reserve base totals 320 Mmt of contained zinc, of which 150 million tons may be considered reserves. Australia (19%), Canada (18%), and the United States (16%) have the largest shares of the world's estimated zinc reserve base. The remaining 47% is distributed among many other countries, principally China, Mexico, Peru, and the former Soviet Union. Zinc deposits tend to be common worldwide but intensely explored countries of large size and geological diversity tend to have the largest reserve base.

Zinc availability in the market economy countries was estimated for 186 operations in 25 countries. Table IIIAiiij-3 shows total recoverable zinc reached 120 Mmt from producing and non-producing deposits. The United States accounts for about of third of available zinc followed by Canada with 18% and Australia with 15%. Australian operations, on average, are the lowest cost producers, followed by the United States and Mexico. Figure IIIAiiij-3 shows the availability of zinc at producing operations. Approximately 45 Mmt are available at under $0.50/lb. zinc.

World Production--In 1990, 7.3 million tons of zinc was mined in 50 countries. The leading 5 producers, (in decreasing order of output) Canada, Australia, the U.S.S.R., Peru, and the United States accounted for 54% of total world output. On a geographic basis the Americas accounted for about 40% of world mine output. Europe, including Greenland and the U.S.S.R.; Asia; Australia; and Africa accounted for 27%, 16%, 13%, and 4%, respectively. Figure IIIAiiij-4 shows the world mine production of zinc from 1960 to 1990.

National Defense Stockpile--A stockpile of zinc for national defense purposes has been maintained by the Government for more than 50 years. Materials in the National Defense Stockpile (NDS), managed by the Department of Defense since July 1988, can be released by the President if deemed necessary for defense or essential civilian purposes.

Figure IIIAiiij-5 shows the NDS contained an inventory of 1.434 Mmt in 1963. Sales of zinc considered excess of goals reduced the NDS inventory to 340 kmt by the end of 1975. A zinc stockpile goal of 1.293 million tons was established in April 1980, but no zinc had been purchased through 1991 to meet this goal. At the end of 1991 the zinc stockpile totaled 343 kmt, including 2,625 tons of zinc contained in brass. Sharply lower goals for zinc have been

proposed in recent years but not approved. In view of the political changes in eastern Europe and breakup of the U.S.S.R., new goals well below the current inventory are likely. Industry stocks, typically have ranged between a 4 and 8 week supply, but in recent years stock levels have tended to be in the 3 to 6 week range owing to increasing preference for just-in-time delivery.

Security of Supply--U.S. zinc mine and smelter production and available capacity meet less than half of U.S. zinc requirements. Although the domestic ore reserve base is large, it would take several years to bring additional mines onstream and domestic smelter capacity would have to be built to process the increased zinc mine output. Deficient zinc smelter capacity also effects the U.S. capability to be more self-sufficient in the production of a number of strategic and critical zinc byproduct materials such as cadmium, germanium, and indium.

Although Alaskan production was expected to account for about half of U.S. zinc mine output in the future, this new output was not expected to improve U.S. self-sufficiency because all of the zinc concentrates are scheduled for export. Even if Alaskan concentrates were redirected to U.S. smelters only, little or no smelter capacity is available to process the material. In 1990 and 1991, for example, domestic zinc mine production substantially exceeded U.S. smelter feed requirements resulting in net exports of about 174 kmt and 350 kmt tons of zinc in concentrate, respectively.

Although imports constitute a large proportion of U.S. zinc supply, about 60% of the zinc metal, concentrate, and compound imports come from Canada and Mexico, and, therefore, the risk of supply disruption is low. Other traditional sources of zinc supply depends on sea transport, and the risk of supply disruption is considerably higher.

Environmental Concerns--Environmental concerns in the zinc-producing sector deal mainly with tailings disposal, water treatment, residue handling, workplace standards, and air quality control. To a large extent in zinc mining and smelting, environmental problems are more associated with coproduct and byproduct elements, mainly lead, cadmium and sulfur, than with zinc. Superfund liabilities associated with mines, mills, and smelters, some of which closed down many years ago, threaten the viability of existing companies not only because of current high cleanup costs associated with past production but also because of potential future costs related to, as yet, unknown and undetermined environmental damage.

Special Issues Related to Forest Lands--No significant issues relative to zinc occurrences on Forest Service lands have been identified.

Fluid Hydrocarbons: Petroleum and Natural Gas

This chapter provides information about historic and projected supply and demand for fluid hydrocarbon resources, sometimes called petroleums. In its broadest usage, the term petroleum refers to a series of closely related complex hydrocarbon compounds of the paraffin, naphthene, and aromatic series (Frick 1962). The paraffin series are the most common in both crude oil and natural gas. The naphthene series contributes to liquid refinery products and its residue from the refining process is asphalt. The aromatic series are present in all petroleums, but usually only in small percentages. The most common member of this group is benzene.

These series occur in innumerable different combinations of varying proportions; in fact, each petroleum is unique. Since petroleums differ greatly in their chemical composition, it is not surprising to find that their physical properties differ too. Some petroleums occur as gases, others as liquids and a few as solids. Natural gas, about which more will be said in the second half of this chapter, comprises the lighter paraffin hydrocarbons. All occur as gases. Liquid hydrocarbons are subdivided into crude oil and natural gas liquids. The former is made up of intermediate to heavy hydrocarbons that occur as liquids both in the reservoir and at the surface. Natural gas liquids are composed of light to intermediate hydrocarbons that exist in the liquid state at the surface. The Energy Information Administration defines petroleum as referring exclusively to the liquid hydrocarbons, a practice which will be followed for the remainder of this chapter.

Fluid hydrocarbons can range from clear to green to black (for some heavy oils). The liquid forms are immiscible in water and float on it (at 60 °F); gaseous hydrocarbons are somewhat soluble in water. These hydrocarbon mixtures also may contain a variety of additional elements or compounds, including sulfur, nitrogen, oxygen, vanadium, nickel, and sodium chloride. Sulfur compounds are heavy and so occur more frequently in the heavier grades of oil; however, lighter grade crude oils and natural gas can contain sulfur. A high sulfur petroleum or natural gas is termed sour.

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[3] Petroleum is measured in standard stock tank barrels of 42 gallons. Large quantities are expressed in thousands, millions, and billions of barrels, Mbbl, Mmbbl, and BBO respectively.

Petroleum

The United States is a major consumer of energy, almost 84 quadrillion Btu's in 1993 (USDOE, EIA 1994). Petroleum has been our most important source of energy since 1950, supplying more Btu's than either natural gas or coal (figure IIIBia-1). Petroleum's dominance results in large part from its importance as a transportation fuel. More than 95% of the energy used by the transportation sector is derived from petroleum, although this preponderance is expected to decrease as alternative fuels such as methane and natural gas are phased-in response to the Energy Policy Act of 1992. The balance of our energy needs are met from a variety of sources, including coal, hydroelectric, solar, and nuclear energy.

Historic Supply and Demand Situation for Petroleum--All through history humans have utilized petroleum found at seeps or recovered from hand dug wells. There is evidence of such usage on every continent and dating back 5000 years to the Sumerians, Assyrians, and Babylonians. However, it has only been in the last one hundred years that petroleum has become essential to society. We have come to depend upon the products produced from it: refined oils, solvents, fuels, and petrochemicals, which in turn are transformed into an endless number of products ranging from fertilizer to plastics. Petroleum in one form or another is also integral to the production of all the other energy and mineral resources reported upon in this study.

Over the past 20 years domestic production, consumption and prices for petroleum have been volatile as a result of both international and domestic factors. One reason has been that U.S. oil producers constitute only one segment of that large worldwide industry and U.S. consumers only one segment of a world market. Actions taken in other parts of the world can and often do affect the domestic market. Moreover, many pieces of Federal legislation directly or indirectly affecting the industry were passed in the 1970's and early 1980's. The affects were passed on to consumers. The

[54] Hereafter Q Btu. A BTU, or British Thermal Unit, is the amount of heat required to raise the temperature of a pound of water by 1 degree Fahrenheit. The use of Btus content allows comparison of physically dissimilar resources, such as coal and crude oil.

following selective chronology of domestic and international events related to the oil industry is provided as background.

In 1970, when domestic oil production peaked, the U.S. had access to cheap and abundant supplies of oil worldwide. However, by 1973 the nation faced its first peacetime petroleum supply disruption as several Arab nations instituted an oil embargo against the United States and Holland. The embargo was lifted 6 months later, leaving world crude oil prices higher and OPEC firmly in control of the world oil market.

During that same year the Emergency Petroleum Allocation Act (EPAA) of 1973 was passed. Its goal was to ensure equitable distribution of available products and establish equitable prices through a two-tier pricing system for domestic oil. "Old" oil from properties producing at or below their 1972 levels would be subject to a price ceiling. "New" and imported oil could be sold at market prices. The result was less exploration and production because most domestic oil could only be sold at prices below the going world rate.

The intent of the Energy Policy and Conservation Act (EPCA) of 1975 was to modify the two-tier price system so as to encourage domestic production and exploration. In retrospect, the program actually provided a slight incentive to import crude oil and as a result domestic on-shore (as opposed to off-shore) production continued to fall through the late 1970's. The Act also created the Strategic Petroleum Reserve and instituted the Corporate Average Fuel Economy (CAFE) standards, intended to encourage increased fuel efficiency. Throughout this period domestic oil prices were held artificially low. Demand increased to its historic high by 1978.

The Iranian Revolution started in late 1978, the Iran-Iraq war in 1980. Between 1978 and 1981, OPEC production declined and world crude oil prices rose dramatically. The high prices stimulated exploration and production in many non-OPEC countries, discouraged consumption and encouraged fuel switching. World and U.S. demand for petroleum fell. Finally, in 1981 the U.S.government removed price and allocation controls and domestic prices were allowed to rise to world market levels. Prices for other forms of energy rose as well. For these and other reasons U.S. economic activity slowed and the country endured a severe recession from mid-1981 through 1982. This encouraged even more conservation and fuel switching and thus lessening the demand for oil. Prices declined somewhat between 1981 and

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[55] This review is based in large part on The U.S Petroleum Industry: past as prologue 1970 - 1992 (USDOE, EIA 1993a). Numerous other comprehensive historical reviews are available, including works by Cremer and Salehi-Isfahani (1991) and Toman (1993).

[56] Organization of Petroleum Exporting Countries.

1983, but consumption continued to fall in part because of the recession.

In 1985, the world oil market changed again. In July it became clear that Britain (with their North Sea production) would not cooperate with OPEC as a de facto fourteenth member. Spot prices began to decline. Then in September Saudi Arabia increased production to their full OPEC quota level of 4.7 million barrels per day. During the first quarter of 1986 the price of oil collapsed, dropping over 50 %. This change, combined with a newly expanding U.S. economy caused renewed domestic demand. U.S. production, however, fell and imports increased again. Prices have since recovered slightly and consumption has increased, though not to the high levels of 1978. Domestic production has continued to decline.

Historic Petroleum Consumption--As noted in the foregoing discussion, and shown in figure IIIBia-1, petroleum consumption in the U.S. has not been steady. It rose from 19.92 Q Btu's in 1960 to a high of 37.97 Q Btu's by 1978, then declined again during the early and mid-1980's. Consumption then rose to 33.77 Q Btu's by 1993. In barrels, this translates to 3.58 BBO in 1960, 6.88 BBO in 1978, and 6.23 BBO in 1992.

These variations have been in response to changes in the price of petroleum, its price relative to other energy sources and the state of the U.S. economy. They represent a pattern that is consistent with the view of petroleum demand as price inelastic in the short-run, i.e., demand as relatively unresponsive to price changes, at least in the short term. For example, it has been estimated that a 1 % increase in gasoline prices will lead to a decrease in demand of only .11 to .41 % (Bohi 1981). The result of this price insensitivity is that market disruptions such as the Arab embargo of 1973 cause sharp changes in price.

Inelastic demand may be caused by a number of factors. The most important in this circumstance may be the fact that switching fuels and energy sources can be complex and expensive. Individuals and firms have made investments in capital equipment (vehicles, manufacturing facilities, power plants) that has specific energy requirements. It cannot always be replaced quickly or costlessly. Over time, however, consumers and businesses can respond to price changes through a combination of fuel switching and the purchase of more fuel efficient vehicles, appliances, and equipment.

[57] Both "spot" and "forward" transactions are made in the oil market. A spot transaction is the purchase of and payment for oil with immediate (more or less) delivery. In a forward transaction, delivery and payment take place at a fixed future date, but price is established at the time the contract is agreed upon.

Examination of petroleum consumption per (1982) dollar of GNP and per capita illustrates this idea (figure IIIBia-2). During the 1960's, a period of economic expansion, consumption decreased in terms of Btu's/$, but increased in terms of Btu/capita. Although the Arab embargo of 1973 affected both measures of consumption for a few years, the trend continued generally upward. However, by the late 1970's consumers and businesses were beginning to respond to oil market uncertainties and price increases. Consumption per dollar of GNP began dropping in 1977 and has continued to do. Per capita consumption decreased from 1978 until 1983, but increased in the late 1980's as oil prices remained low.

Historic Domestic and World Petroleum Production--U.S. crude oil production peaked in 1970 at 3,518.6 million bbls (table IIIBia-1). Production declined in the late 1970's, but rose again in the early and mid-1980's, reaching 3,274.0 million bbls in 1985. Total production has since declined to 2,617.1 mm bbls by 1992. Preliminary estimates place 1993 production at 2,496.6 bbls, a level lower than any seen in the last 30 years.

World petroleum production stood at 7,650.4 million barrels in 1960. At that time, OPEC supplied 41.4 % of the oil and natural gas liquids, the U.S. 33 %. OPEC'S share of world production increased to 51 % by 1970, but slipped back to 41.4 % of production by 1992. This percent represented 9,106.75 million bbls of petroleum, slightly less than 3 times the amount OPEC produced in 1960. As noted above, U.S. production overall and as a share of world petroleum production has dropped steadily during this period. By 1992, it had slipped to 11.9 % of the 21,994.9 million bbls produced worldwide.

Petroleum Imports--The result of this disparity between domestic production and consumption is that the U.S. is an importer of petroleum. Net imports of crude oil and petroleum products peaked in 1977 at 3.1 MMbbls (figure IIIBia-3). Although imports dropped in the early and mid-1980's, they are again approaching the highs seen in the late 1970's. As of 1992, net imports (2.5 MMbbls) represented approximately 41 % of total petroleum supplied. Preliminary estimates put 1993 imports at 44 % of total product supplied.

Petroleum Prices--As previously noted, petroleum supply and demand are both characterized by short-run inelasticity, i.e., a one percent change in price leads to a less than one percent change in either supply or demand in the

near term. When this situation combined with fluctuations in actual supply and demand, as well as government and cartel market manipulation, the result is volatile prices. Table IIIBia-2 reports historic and projected prices for petroleum. There are many market prices for crude oil; spot, future, bench mark, etc. The historic prices reported here are U.S. average first purchase price for crude oil as reported by the USDOE, EIA 1994. Previously discussed events related to the oil industry are pegged to real prices in figure IIIBia-4.

Future Petroleum Consumption--Petroleum plays a central role in the U.S. economy and is expected to do so into the next century. Demand will depend upon numerous factors, including the relative price of petroleum and consumer preferences across energy alternatives. Consumption projections from the National Energy Strategy (1992) are reported below. These forecasts differ somewhat from those reported by USDOE, EIA in the Annual Energy Outlook (1993b) due to differences in assumptions. The latter report was not utilized here because it forecasts consumption and production only to 2010.

The Department of Energy has published two long term forecasts of energy demand (table IIIBia-3). Each is dependent upon a variety of important assumptions regarding such issues as GNP and population growth rates, the availability of resources, rates technological change, conservation measures, alternative energy sources and the world price of oil. Although it is beyond the scope of this report to review all the DOE assumptions, several of them differ significantly between the Base Case and National Energy Strategy scenarios and warrant discussion here.

In the Base Case, DOE has assumed there will be continuing gains in the energy efficiency of the U.S. capital stock, an overall 32 % gain by 2030. Continuing decline in energy consumption per dollar of GNP is also assumed. This is consistent with the trend illustrated above. Nonetheless, primary energy consumption is expected to increase at an average rate of 1.3 % per year.

The Base Case assumes that renewable energy sources will provide an increasing percent of the total energy.

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[58] The Forest and Rangeland Renewable Resources Planning Act (1974) requires 50 year forecasts; however, the reader should bear in mind that the confidence intervals on values far in the future are very broad. Forecasts of energy demand for the years after 2030 are based upon extrapolation of the trends reported in the National Energy Strategy (DOE 1992) for the 2025 to 2030 period.

[59] DOE's assumptions regarding GNP and population growth differ slightly from those published by RPA (USDA Forest Service 1989).

Geothermal, wind, photovoltaic, solar thermal and other diverse sources are expected to supply as much as 12 % of our energy by 2030. However marketplace obstacles are expected to limit ethanol production to 200,000 bbls/day of oil equivalent and to preclude methanol imports. Concern about air quality could lead to increased consumption of both these fuels. If this were to happen, the DOE Base Case forecast could over estimate the demand for petroleum.

The Energy Strategy Case assumes significantly higher gains in energy efficiency than does the Base Case, 42 % by 2040. These gains are the result of integrated resource planning, changes in building standards, and successful research and development efforts. The result is growth in overall energy consumption of slightly less than 1 % per year.

Alternative fuels and biofuels are assumed to capture 18 % of the energy market by 2030 in the Energy Strategy Case. Renewable energy consumption is expected to increase in the electricity generation and transportation fuels sectors. In this scenario the use of alcohol fuels expands substantially compared to the Base Case. Finally, there are assumed to be increases in nuclear power generation.

The alternative assumptions lead to very different long term trends in petroleum consumption. Under the Base Case scenario, U.S. consumption grows continuously, reaching 52.0 Q Btu in 2030 and 54.5 Q Btu by 2045 (9.42 BBO and 9.87 BBO respectively). Conversely, under the Energy Strategy scenario, petroleum consumption peaks in 2015 at 38.3 Q Btu, dropping to 35.6 Q Btu by 2030, and 32.7 by 2045 (7.08 BBO, 6.50 BBO and 5.98 BBO respectively).

Petroleum Geology--As the USDI, Geological Survey (Mast et al. 1989, p.7) has noted "The distribution of oil and gas resources in the United States is best understood within the framework of the geology of the North American Continent." Although it is well beyond the scope of this report to discuss the entire field of petroleum geology, several introductory points are mentioned.

There are two schools of thought on the genesis of oil: the organic theory and the inorganic theory. According to the organic theory petroleum is generated from organic matter. This material accumulated in marine sediments such as deltas and when subjected to the heat, weight and pressure of thousands of feet of overlying sediment, oil and gas were produced. The inorganic theory holds that hydrocarbons come from deep in the earth, from source materials present since the formation of the planet. This view is not as widely held as the other.

Petroleum geology involves the study of two principal kinds of sedimentary rocks: source rocks and reservoir rocks. Source rocks contain considerable organic material. They must have been permeable at one time, in order for the petroleum to flow from them to the reservoir rocks, where it has accumulated. Many source rocks are shales. The best reservoir rocks are porous, i.e., they contain spaces to hold petroleum. They are also permeable, and the spaces are connected so that the petroleum can flow toward wells and be easily produced. Some of the most productive reservoir rocks are sandstones and limestones.

Petroleum is less dense than rock. If not contained, it will flow upward. Petroleum accumulates in pools, or traps, within reservoir rocks. The two basic types of reservoir traps are structural and stratigraphic. Structural traps include anticlines and faults. Through time, blocks of earth have been shoved upward, dropped downward, or moved laterally. The rocks fold and break, forming various shapes in which petroleum can be contained or "trapped." In the anticlinal trap, a good reservoir rock layer is folded so that it forms a dome or ridge. Oil flowing up along the layer is trapped at the highest point of the anticline. In fault traps, the reservoir rock has been broken by a fault. Oil flowing up along the layer stops where the reservoir rock ends, pooling against rocks that are much less porous and permeable.

Stratigraphic traps are formed where the characteristics of a reservoir rock layer change so that it becomes a much less favorable reservoir. Oil flows up along the porous and permeable reservoir rock layer, accumulating when it reaches an area with much less porosity or permeability. Stratigraphic traps are sometimes called pinch-outs.

Oil and gas resource estimates are reported by petroleum province, the boundaries of which are based on geologic features (Mast et al. 1989). The distribution of desirable source and reservoir rocks is not even and some provinces are thought to hold higher resources than are others. Areas possessing deep sedimentary basins, i.e., depressions in the basement rock filled with sediment such as the Anadarko Basin in Oklahoma, are often highly productive of oil and gas (figure IIIBia-5). The probability that a major new oil field will be discovered outside one of these basins is relatively low.

Petroleum Reserves and Resources--A standard terminology is used in the resource estimation community. The definitions of these terms and their associated diagrammatic representation were presented in Section IIB of this report and will be only summarized here. The term resource refers to desirable material in the earth's crust in such form that

economic extraction is currently or potentially feasible. Measured and indicated reserves are the subset of that resource that are expected with reasonable certainty to be economically recoverable. The "proved reserves" as used in the oil industry is generally equivalent to measured reserves. Inferred reserves are economic resources expected to be added through extensions and revisions in already discovered oil and gas fields. Undiscovered resources are those estimated to exist based on geologic knowledge and theory. Recoverable undiscovered resources are presumed to be producible with existing technology. This production may be currently economic or uneconomic.

Onshore crude oil reserves as of December 31, 1991, for the 48 states plus Alaska, were 22.7 BBO (USDOE, EIA 1993c). Total U.S. reserves (including offshore) as of January 1, 1993, were reported to be 23.7 BBO. In addition to covering a broader geographic area, the difference in these estimates reflects removals from reserves due to production and additions to reserves through discovery.

Petroleum reserves outside the U.S. are substantially larger than those discussed above (table IIIBia-4) (USDOE, EIA 1993c). World reserves are reported to be slightly less than 1 trillion barrels. Reserves are highest for the Middle Eastern region at 661.8 billion barrels. (Bear in mind also that these are "proved" reserves; there are undoubtedly an even greater volume of resources.) U.S. reserves represent only 3.6 % of those in the Middle East and 2.4 % of those reported worldwide.

Total domestic recoverable crude oil resources, including off-shore and on-shore, are in the range of 98.0 to 144.0 BBO (table IIIBia-5) (USDOE, EIA 1990). This figure represents reserves plus inferred and undiscovered resources. The lower value assumes current technology. The higher figure is based on improved access to resources (small increase) and use of improved technology (larger increase).

Naval Petroleum Reserve--The Taft and Wilson Administrations set aside "naval oil reserves" as a result of the pre-World War I debate about converting the U.S. Navy from coal to oil. After much political turmoil, Federal leasing to

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[60] The reserve quantity listed in table IIIBia-4 is an end of 1988 estimate. EIA reports reserves as of January 1, 1993 at 23.7 BBO.

[61] Oil and gas are not included in the National Defense Stockpile, which was established to store quantities of strategic minerals and metals.

private oil companies began in the spring of 1922. The "Teapot Dome" scandal caused the government to cancel the leases and the reserves were withdrawn from further private development.

In 1976, the Naval Petroleum Reserve Production Act was officially established. Since its establishment, the Naval Petroleum Reserve (NPR) has been placed first under the authority of the Dept. of the Navy, then the Dept. of the Interior, and finally the DOE. The Act provides for allocating NPR reserves of oil for defense, if needed. Reserves can also be transferred to the U.S. Strategic Petroleum Reserve. However, since 1976, most oil produced from the NPR has been sold on the open market at an average rate of 70,000/bpd, or about 4% of U.S. consumption. The U.S. Treasury has received over $11 billion in net revenues (USDOE, EIA 1993c).

U.S. Strategic Petroleum Reserve--During the 1973 oil shock, foreign and domestic supplies, as well as U.S. consumption levels, of petroleum were disrupted by the changing price of crude. The price of oil was $1.95/barrel in 1953, $1.80/barrel in 1965-1970, but escalated dramatically to $5.11/barrel on October 1973. By January 1974, the price was $11.65/barrel (in nominal dollars).

Since that time the industrial countries have developed an energy security system built around the International Energy Agency and strategic stockpiles, such as the U.S. Strategic Petroleum Reserve (SPR) and similar reserves in Germany and Japan. These are designed to avert shortfalls and counteract market panics. The SPR, established in October 1977, consists of petroleum that is produced and then stored in salt domes in Louisiana.

In 1993, the SPR contained 587 MMbbls of petroleum, or 63.6% of total U.S. crude oil stocks. This represented 78 days of net petroleum imports. However, according to the SPR, draw downs could be staged over 360 days.

In contrast to the National Defense Stockpile, the SPR reserves have been used to control consumer prices. During the recent Persian Gulf War, the U.S. government sold (drew down) 17 MM bbls, the first crude oil stocks removed from the SPR's inventory.

Future Petroleum Production--Future supply will be dependent upon the discovery and development of economic resources to replace depleting reserves. The Department of Energy has estimated long term domestic petroleum oil production under the Base Case and Energy Strategy scenarios discussed above (1992). Given Base Case assumptions,

oil production is predicted to decline steadily, reaching 2.01 BBO in 2030, for a loss of 609 million bbls or 23 % from 1992 levels. If that trend were continue, production could be as low as 1.34 BBO in 2045. In terms of Btu's, production declines from 18.9 Q Btu in 1989 to 8.8 Q Btu by 2030, and to only 5.5 Q Btu by 2045.

The Energy Strategy Scenario includes expanded access to domestic resources, various incentives for production and advanced oil research and development. The result is a substantial increase in output during the period up to 2005, when production is expected to peak at 4.31 BBO (equivalent to 21.9 Q Btu). Production is expected to decline thereafter, sinking below 1992 levels by 2030 (2.23 BBO or 10.9 Q Btu).

Projected Supply and Demand Balance--As reported above, the DOE has predicted petroleum consumption and production under two possible scenarios. Given Base Case assumptions, domestic production continues to decline, while consumption rises inexorably. The result is a widening resource imbalance. In 1990, domestic oil production fulfilled 56% of domestic consumption. By 2030, this ratio is expected to decline to just 17% in terms of Btu's and 21% in bbls. Imports will obviously have to increase if this scenario comes to pass.

The Energy Strategy Case includes assumptions regarding increased conservation and use of alterative energy sources. Although petroleum consumption increases during the first 15 years of the next century, the long term forecast trends downward. On the supply side, petroleum production is forecast to increase until 2005 and drops off thereafter. This leads to an ever widening imbalance between output and use. By 2030, domestic production is predicted to fulfill 31% of consumption in Btu terms, decreasing to 22% by 2045 if the trends continue. In terms of bbls the ratios are 34% and 24% respectively. Again the U.S. will be dependent upon oil imports, though the amounts are reduced by almost half.

In theory, prices are determined by the interaction of supply and demand in a competitive market place. But as the discussion of recent events made clear, the world market for petroleum is not a purely competitive market. Actions by the producer cartel (OPEC) and by various governments, including that of the United States, have impacted the price of oil. The situation is further complicated by the issue of exhaustibility. The supply price of a nonrenewable resource such as oil does not equal the marginal cost of production. Rather it includes an additional amount, called scarcity rent, that

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[62] This figure is based on extrapolation of the 2025-2030 trend estimated by DOE.

[63] Adelman (1993) does not consider oil a nonrenewable resource, arguing instead that higher prices inevitably lead

represents the opportunity cost of precluding extraction in the future by extracting now. All this make price forecasting an inexact science.

The price projections reported in table IIIBia-2 were developed by the DOE as part of the National Energy Strategy, Base Case (DOE 1992). Constant dollar prices are forecast to increase to $37.51/bbl by 2030, and $42.63/bbl by 2045. This represents a significant increase over current prices. (It should be noted that price forecasts after the year 2030 are trend extrapolations of DOE forecasts.) These projections are based on a set of assumptions and as the Energy Strategy Case demonstrates, different assumptions lead to different price forecasts. Under this alternative scenario oil prices reach only $32.66/bbl in 2030, and $35.02 in 2045.

Natural Gas

Natural hydrocarbon gases are closely related to the liquid hydrocarbons. They are composed principally of hydrocarbons in the paraffin series, plus carbon dioxide, nitrogen, and helium. The paraffin hydrocarbons of primary concern in gas processing operations are methane, ethane, propane, butane, pentane, hexane, heptane, octane, nonane, and decane - listed from lightest to heaviest - gases to liquids. Natural gas is termed either wet or dry. Wet gas contains some heavier hydrocarbons, which at the surface condense to form a liquid. Dry gas contains no hydrocarbon liquids. Condensate wells produce a natural mixture of gaseous and liquid hydrocarbons.

Natural gas occurs either by itself or in conjunction with crude oil. In oil wells, the gas may be dissolved in the oil (solution gas), similar to the carbon dioxide in a can of soda pop. Alternatively, it may be separated from the oil (free gas). In either case, gas provides a driving force that facilitates oil production. As a result, it is often reinjected into the producing geologic formation to maintain reservoir pressure at desired levels.

Natural gas has been gaining popularity in recent years for environmental reasons. Unlike other hydrocarbons,

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to discovery of new resources and reserves.

[64] Natural gas is usually measured in standard cubic feet. Large quantities are expressed as thousands, millions, trillions or billions of cubic feet, Mcf, Mmcf, Tcf and Bcf respectively.

natural gas burns completely, leaving only carbon dioxide and water as waste products. It has a higher level of thermal efficiency and fewer impurities than either coal or oil. There is, however, potential for the production of nitrogen oxide, which can contribute to photochemical smog.

Historic Supply and Demand Situation--Natural gas has been burned for heat for at least 2000 years (Berger and Anderson 1992), but certain of its physical properties limited the extent of use until well into this century. Natural gas has low density and viscosity. Lacking either definite shape or volume, it will expand to fit the space in which it is stored. In other words, it will dissipate in the atmosphere unless captured in an enclosed system at the wellhead. This characteristic has made natural gas challenging to transport and store.

In ancient China, wells were connected to distribution systems made of bamboo poles; in the U.S. bored-out white pine logs were used as early as 1870 (Medici 1974). Both types of approaches suffered from leaks, failures and were infeasible over long distances because pipeline pressure could not be maintained. And so, prior to the development of transport technology, gas had to be marketed near the producing field or else be released into the air as a waste product. Large volumes of associated gas were flared or vented, a practice still common in some parts of the world, such as the Middle East. As the following historical survey makes clear, the natural gas industry did not really grow until after transport methods were developed in the 1930's.

Recent Events Affecting Natural Gas Markets--All segments of the natural gas industry, production, gathering, transportation, and end use, have been affected by government regulation as the following selective, historical survey of gas regulation makes clear (Griffin and Steele 1986).

The U.S. Natural Gas Act, passed in 1938, created the Federal Price Commission (FPC), and charged it with regulating interstate gas pipeline companies. This was an era of monopoly regulation and pipelines came under government scrutiny because they had a characteristic typical of natural monopolies: per unit costs fell as volume increased. Subsequent regulation was intended to preclude monopoly pricing behavior by pipelines.

Gas prices did in fact remain low throughout the 1940's, though largely because a lack of pipeline capacity limited demand. After World War II, two pipelines previously used for crude oil and products were converted to natural

gas lines (Petroleum Extension Service 1981). As these and other new pipelines were completed, large scale, long distance gas transmission became feasible. Demand grew in new markets, such as the northeastern U.S., and prices rose ten-fold.

In 1954, the Supreme Court ruled that the FPC's authority actually extended to regulating the price of gas sold in interstate markets. Unfortunately, the cost-based price regulations that worked for natural monopolies like pipelines and utilities, weren't directly applicable to gas producers. High-cost producers who had been assigned high prices by the FPC were unable to complete with lower cost producers who had been assigned lower prices. Conflicts between producers and the FPC over rate assignments numbered in the thousands.

In 1959, following another Supreme Court ruling, the FPC began area pricing. "New" gas and "old" gas were to be sold at different regulated prices in interstate markets. Intrastate sales remained unregulated, and as a result, much of the "new" gas was sold intrastate at competitive prices. By 1977, the price differential between "old" and (intrastate) "new" gas was seven-fold. Gas available for interstate sale was mostly "old" gas. Not surprisingly, all this led to gas shortages in nonproducing states.

Gas decontrol finally began in 1978 with the passage of the Natural Gas Policy Act. Although "old" gas still could not be sold at competitive market prices, certain categories of "new" gas were to be decontrolled over time. In addition, tax incentives were awarded for finding gas. In the short run, however, the Act actually increased regulation. The number of price categories was increased to 27 (this for a homogeneous commodity) and intrastate sales were brought under the purview of the Federal Energy Regulatory Commission (successor to FPC).

Prices rose, and with them production rates. The combination of increased gas supply and decreased demand forced prices back down again. (Consumers were switching back to oil as its relative price dropped.) Producers shut in wells rather than sell at what they considered unreasonably low prices.

Deregulation was furthered by the Natural Gas Wellhead Decontrol Act (1989). Since that time the focus of Federal policy initiatives has been deregulation and the promotion of competition in the market. Nonetheless, an excess of supply and resultant low natural gas prices have continued into the 1990's (Johnson 1992).

Historic Natural Gas Consumption--According to the USDOE, EIA 1994, the vast majority of natural gas is

currently consumed in four markets: residential consumers (23%), commercial (14%), industrial (44%) and electric utilities (15%). The remaining gas is used as lease and plant fuel and as pipeline fuel. In 1990, about half of all U.S. residential utility customers heated their homes with natural gas, using approximately 4.4 Tcf. Although the number of customers has steadily increased since 1986, their overall consumption of gas has actually declined due to warmer atmospheric temperatures and various conservation methods, including more efficient appliances and installing storm doors and windows. Demand in the commercial sector is also determined by basic heating requirements, so weather significantly affects consumption in these market segments. Industrial and utility consumption are dependent in large part on price of natural gas in relation to alternative fuels, its availability, and the level of economic activity.

U.S. consumption of natural gas rose steadily during the 1950's and 1960's, peaking in 1972 at 22.7 Q Btu (table IIIBib-1, figure IIIBia-1). Consumption sank to 20.4 Q Btu by 1980 and 16.7 Q Btu by 1986. In recent years, consumption has recovered and preliminary estimates put 1993 quantities (20.8 Q Btu) at the highest level since 1974. In physical units, consumption was 22.1 Tcf, 19.9 Tcf, 16.2 Tcf, and 20.2 Tcf respectively (figure IIIBib-1).

Current demand for natural gas also reflects market perceptions about the dependability of deliveries. As noted above, there have been instances in the past of shortages in nonproducing states; interstate deliveries were not made either because gas was not available or the previously agreed upon selling price was deemed too low. Regulations caused part of the problem; however, a lack of coordination between the 5000+ producers, 45 independent pipeline companies, and numerous buyers may have contributed as well. If demand is to rise in the future, concerns about the reliability of deliveries will need to be assuaged.

Historic Natural Gas Production and Imports--World and U.S. natural gas production is reported in table IIIBib-2 in physical and energy units. U.S. production peaked in 1972 at 21.73 TCF. Output fell throughout the remainder of the 1970's and much of the 1980's, reaching a low of 16.06 TCF in 1986. It has since recovered slightly. During the same period, world natural gas production steadily increased, reaching 75.0 TCF in 1992. In contrast, U.S. production was lower in 1992 than it had been 20 years earlier.

Gas production is largely demand driven, in part because of the difficulties and costs associated with tank or

[65] Percentages are based on 1990 consumption data.

underground storage of excess supply (DOE 1992). As a result, U.S. production has closely followed consumption (figure IIIBib-1). Consistent with this relationship, imports have until recently accounted for only a small part of the U.S. natural gas market. The majority of imports arrive via pipeline from Canada or Mexico. The balance are shipped in the form of liquified natural gas (LNG) via ship or truck.

Natural Gas Prices--As was the case with petroleum, natural gas prices have been volatile. While this industry sector has not faced the market impacts of powerful a powerful cartel, it has clearly been impacted by government market intervention. Table IIIBib-3 reports historic and projected prices for natural gas. The historic prices reported here are U.S. average wellhead price as reported by the USDOE, EIA 1994. Real prices are graphed in figure IIIBib-2. (Price projections are discussed at the end of the section on Projected Supply and Demand.)

Projected Supply and Demand--The clean burning properties of natural gas make it an increasing popular source of energy. Future demand will depend upon its price relative to other energy sources and also on availability. As with oil, future supply will be shaped by the identification of proven reserves. In addition, production will be impacted by technological advances needed to make unconventional resources economically viable. But perhaps most importantly, the gas market will continue to be affected by the types and degree of government regulation in place. Consumption and production estimates reported below were developed by the USDOE in support of the National Energy Strategy.

Future Natural Gas Consumption--The USDOE has estimated future natural gas consumption under two scenarios (USDOE 1992). The assumptions behind these scenarios were discussed in the preceding petroleum demand section and will not be repeated here with one exception. Because future market conditions will be affected by governmental regulations, the Energy Strategy Case assumes the following regulatory actions: reform of natural gas pipeline certification, deregulation of pipeline rates, improved third party access to pipelines, and elimination of import and

[66] For natural gas to be transported by tanker, it must be in a liquid state, which is accomplished by reducing the temperature below -259 F. LNG should not be confused with liquefied petroleum gases (LPG) such as propane that are produced from crude oil.

[67] Forecasts for years after 2030 are based on trend extrapolation of DOE's estimate for 2025-2030.

export restrictions.

In the Base Case, consumption is predicted to rise to 23.8 Q Btu's by 2015 (23.3 Tcf), declining thereafter (table IIIBib-4). The increases are attributed to greater use of gas as fuel in electric power generation. After 2015, natural gas is displaced in the utility market by coal and coal gasification, but retains its market share in the residential and commercial sectors.

The Energy Strategy scenario predicts slightly greater natural gas consumption in the short and medium terms than does the Base Case. Consumption peaks in 2000 at 24.7 Q Btu's (24.2 Tcf), but remains relatively high through 2020. Gas demand in the transportation sector increases as a result of alternative-fuel policy actions. Nonetheless, consumption is predicted to decline to 1950's levels by 2045.

Natural Gas Reserves and Resources--Total world reserves were reported to be 4,883.3 Tcf as of January 1, 1993 (table IIIBia-4) (USDOE, EIA 1993c). U.S. natural gas reserves as of that date were 165.0 Tcf, only 3.4% of the world total. As was the case with petroleum, several regions are reported to have extensive reserves. The Middle East, for example, contains 1,520.1 Tcf of gas, Eastern Europe and the Former U.S.S.R. another 1,960.4 Tcf.

Total domestic recoverable natural gas resources, including off-shore and on-shore, are in the range of 929.5 to 1,339.3 Tcf (table IIIBib-5) (USDOE, EIA 1990) This amount represents reserves plus inferred, undiscovered, and unconventional resources. The lower value assumes current technology. The higher level is based on improved access to resources (small increase) and use of improved technology (larger increase).

Unconventional Resources--Currently, the majority of natural gas is produced from conventional resources, those that exist in conventional reservoirs and for which discovery and production technology are reasonably well understood. They tend to occur as discrete accumulations (Mast et al. 1989). Unconventional resources include extremely viscous heavy oil deposits, tar sands, and gas from low-permiability "tight" sandstones and shales, geopressured shales and brines, or coal bed methane. These are considered separately from conventional resources because of technical difficulties associated with their extraction. The natural gas resource values published by USDOE, EIA 1990, and reported above, include estimates for gas produced from tight sands and Devonian shale, as well as coal

bed methane. All 3 are expected to be important contributors to hydrocarbon production in the future.

Tight formations are those which have in situ permiabilities for gas of less than 0.1 millidarcy. Production requires heavy fracturing of the formation. Devonian shale formations also require massive fracturing of the formation, plus advanced recovery techniques. Tight sands gas is already being produced in the Rocky Mountains, Colorado Plateau, Mid-Continent, and Gulf Coast. Development of these resources to date has been facilitated by tax incentives.

Methane is found naturally in coal deposits, but until recently was viewed as a safety hazard rather than a resource. It is formed as a byproduct of coalification, the process through which plant material is progressively altered from peat to lignite to bituminous and finally anthracite coal. The methane may be dissolved in ground water in the coal bed, adsorbed to the coal surface or free in pores or fractures. The size of the coal bed methane resource is fairly well known, but its producibility is less clearly understood due to various technical challenges (Rightmire et al. 1984). Coal bed methane is currently being extracted in the Black Warrior and San Juan Basins.

Future Natural Gas Production-- USDOE (1992) estimates of natural gas production through 2030 (with trend extrapolations through 2045) are reported in table IIIBib-4 in energy and physical units. Under both the Base and Energy Strategy Case scenarios production is predicted to increase until 2015 and decline thereafter. Gas production is expected to essentially match increasing consumption in the short and medium runs and then decline as alternative fuels (nuclear and renewables) replace gas in utility markets.

Projected Supply and Demand Balance--Although the USDOE forecasts of natural gas production and consumption reported above show a widening disparity between consumption and domestic production the disparity never reaches the proportions seen in the petroleum market. In 1990, domestic production fulfilled almost 92% of domestic gas requirements (in Btu terms). Under the Base Case scenario, this ratio is predicted to decrease to 88% in 2015, falling to 87% in 2030 and 84% in 2045. Ratios are only slightly different in the Energy Strategy Case. The result will be increasing import dependence.

Future natural gas prices will depend upon trends in demand, the price and availability of alternative energy

[68] Ratios of production to supply reported in Tcf do not differ significantly from those reported in terms of Btus.

sources, and replacements to reserves. The USDOE has projected natural gas prices as part of the National Energy Strategy (USDOE 1992). Constant dollar (1982) prices in the Base Case scenario (table IIIBib-3) are predicted to climb steadily, to $6.11/Mcf by 2030, and $7.41/Mcf by 2045 (based on trend extrapolation.) Under the Energy Strategy Case prices are slightly lower, $6.01/Mcf in 2030 and $7.05/Mcf in 2045.

Fluid Hydrocarbon Issues--The most important issue regarding fluid hydrocarbons is clearly security of supply. The United States holds a relatively small percentage of the worlds' petroleum and natural gas resources. The country is currently a net importer of both petroleum and natural gas, a situation which can be expected to continue. Petroleum import dependence is currently over 40% and is forecast to rise to 70% under the National Energy Strategy Base case (USDOE 1992). Import dependence for natural gas is much lower, approximately 7% of current consumption but is predicted by DOE to rise to 13% or higher after the turn of the century. Disruption of shipments from foreign sources of oil could lead to increased interest in exploration, drilling, and production on public lands. Similarly, an increase in the share of the energy market held by natural gas could lead to more gas exploration and development on NFS and other public lands.

Solid Hydrocarbons: Coal

Introduction

This chapter provides information on the historic and projected supply and demand for solid hydrocarbon resources, i.e., coal. Coal is a rock of organic origin. It has been created over millions of years by geologic processes that compressed and heated plant materials. Coals can be classified by hardness and heating value; the higher the heat value and greater the hardness, the higher the "rank" of the coal. Market prices and costs of production differ across the ranks of coal. Standard ranks are (National Coal Assoc. 1993):

[69]Potential environmental concerns associated with petroleum and natural gas development have been addressed in sections IIE and IIF, covering technology and environmental impacts respectively.

Lignite--A brown-black coal with high moisture content (up to 45%) and lower heating value (4,000-8,300 Btu/lb). Carbon content ranges between 25-35%. This type of coal is used in power plants and is mined in Louisiana, Montana, North Dakota, and Texas.

Subbituminous--A dull black coal with moisture of 20-30%, carbon content of 35-45%, and heat value of 8,300-11,500 Btu/lb. It is used by power plants for electricity generation and for space heating and is mined mainly in Montana, Wyoming, Colorado and New Mexico.

Bituminous--This "soft coal" has low moisture (<20%), higher carbon content (45-86%), and higher energy content (10,500-15,000/Btu/lb). It is mined in Appalachia and the Midwestern United States and is used at power plants.

Anthracite--This "hard coal" has the lowest moisture levels of the 4 ranks (<15%), and well as the highest carbon content and heating value (86-97%, and 15,000Btu/lb respectively.) Almost all anthracite mining in the United States takes place in Pennsylvania. It is used for space heating and power generation.

Coal is also classified by sulfur content. the USDOE, EIA groups coals into the following 3 categories:

Low - 0.6 lb of sulfur/MM Btu;

Medium - 0.61-1.67 lb of sulfur/MM Btu; and

High - 1.68 or more lb of sulfur/MM Btu.

Sulfur content is of concern due to the environmental affects of SO_2 discharged as coal is burned. New technologies being developed to minimize sulfur dispersion are discussed in Section IIE of this report.

Coal production, reserves and resources are reported either by region or are grouped as east or west. East refers to the area east of the Mississippi River, west or western to west of the Mississippi River. The regions are as follows: Appalachian Region:AL,GA,eastern KY,MD,OH,PA,TN,VA,WV; Interior Region: AR,IL,IN,IA,KS,western KY,LA,MO,OK,TX; Western: AK,AZ,CA,CO,MT,NM,ND,UT,WA,WY. Figure IIIBii-1 illustrates coal fields in the

lower 48 states.

Historic Coal Consumption

Coal has been used as a heat source since ancient times, but only became the primary commercial fuel source for Europe and the U.S. as populations grew and forest resources depleted. Coal exploitation was integrally associated with the Industrial Revolution in Europe during the eighteenth century and in the U.S. during the nineteenth century. The invention of the railroad (steam) locomotive and steamships led to greatly increased coal utilization because both technologies required a less bulky, more uniform, and higher heat content fuel source than wood.

Just as coal had replaced wood as the primary fuel source in the eighteenth and nineteenth centuries, liquid and gaseous fuels (oil and natural gas) began to replace coal as the primary source of heat energy in the twentieth century. Although consumption rose during WWII, coal lost market share to other fossil energy sources after the war. This situation was reversed in the mid-1970s when oil and gas prices increased dramatically and oil was often in short supply as a result of the oil embargo imposed on the United States and Holland by the Organization of Petroleum Exporting Countries (OPEC). (Figure IIIBia-1 in IIIBia illustrates relative market shares in recent years in Btu terms.)

The embargo demonstrated the U.S. dependence on foreign sources of petroleum and numerous studies of alternative energy sources were undertaken. National energy policy makers investigated processes such as gasification and liquification to convert raw coal to a cleaner, more useable gaseous or liquid state. It was hoped that the conversion of coal would allow for the use of our abundant coal resources and less dependence on foreign petroleum sources.

Congress established the U.S. Department of Energy to replace the Energy Resource Development Agency (ERDA) to tackle the so-called "energy crisis". The U.S. government established a goal of energy independence from foreign sources and published various studies including "Project Independence" outlining our energy resources, market

[70]Market demand for a product is theoretically derived by aggregating across the demand curves of individuals in society. Economic theory indicates that the basic determinants of product demand are own-price, cross-prices or prices of all other goods and services, and income which is generally given as a budget constraint. It is difficult to empirically estimate demand curves since they are determined by individual tastes and preferences and economic situation. Hence, product demand is frequently represented by the level of consumption of a product at various price levels. In this study, demand is defined as consumption.

conditions, and public policy suggestions. The Powerplant and Industrial Fuel Use Act of 1978 and other legislation attempted to redirect consumption back to coal whenever economically feasible. However, with less volatile oil prices, changes in OPEC policies, and international competition that has driven down prices, petroleum regained market share.

The distribution of coal consumption among economic sectors changed over the years as well (figure IIIBii-2) (USDOE, EIA 1994). Railroads began a massive switch from coal to diesel-fueled engines in the mid-1940's. Their coal consumption declined from 125 million short tons (MMst) in 1947 to 15 Mmst by 1955. By 1960, consumption by the railroad industry was minimal, about 2 Mmst. A similar change in consumption occurred in the residential sector with consumption falling from 119 Mmst to 29 Mmst between 1945 and 1960. Industrial and manufacturing sectors' consumption have also declined since the end of World War II.

Coal remains the primary fuel source for the steam-electric generating industry, and in fact the electric utility industry has increased its consumption of coal since the war (USGAO, 1981). Consumption by this sector increased from 83,963 Mmst in 1949 to 772,315 Mmst in 1991, and as a result coal's share of the power generation fuel market rose from 17.4 % to 86.9 % over the same period. The demand by electric utilities has been promoted in part by postwar natural gas price controls that caused gas shortages and made gas less desirable as a source of fuel for large new steam electric generating facilities (Zimmerman 1981). Potential competition from nuclear power generation that would have lead to reduced consumption of coal by electric utilities has not been realized. The nuclear power industry has been plagued by construction delays, regulatory constraints and retrofitting, loss of public confidence as to the safety of the technology, and large cost overruns.

Attempts to further exploit U.S. coal reserves have diminished because gasification, liquefaction, and other conversion processes have not yet been shown to be economically viable in today's energy market. Over time coal has lost relative market share to oil and gas because it is more dangerous to extract; requires expensive technology to reduce adverse environment impacts; is relatively bulky and less easily transported than fluid hydrocarbons; is not generally located near major energy consuming centers; and contains less heat content by weight and unit volume than oil or gas.

Another factor that has inhibited growth of coal consumption relates to government regulations designed to

[71]Coalbed methane is being extracted in a few areas, but it is unclear whether the current level of activity would be maintained if tax incentives were removed. See Unconventional Resources in IIIBiia.

minimize adverse environmental impacts of its use. Legislation and regulations have been enacted that attempt to control effluent discharges from coal-fired electric generating facilities and other direct consumption facilities. Most notable of these are the Clean Air Acts beginning with the Clean Air Act of 1967 and its amendments of 1970 that placed restrictions on emissions of sulfur dioxides and particulates. A series of increasingly more stringent standards has increased the cost of consuming coal and therefore diminished coal's competitive advantage over alternative fuel sources.

Nonetheless, coal continues to be heavily utilized in this country, and around the world, because: 1) it is abundant in certain areas of the U.S. and the world and 2) has a lower price per Btu than other fossil fuel sources (figure IIIBii-3). The latter characteristic will be particularly important if coal is to maintain or increase its energy market share.

Historic Domestic and World Coal Production

U.S. coal production increased steadily after WWII and peaked in 1990 at 1,029 Mmst (table IIIBii-1). Since that time production has decreased slightly, but remains more than 200 Mmst/yr higher than was the case in the early 1980's. Coal production from eastern mines has increased slightly over the last 30 years, but that from western mines has grown dramatically (figure IIIBii-4). The western mines tend to be open large pit operations extracting low sulfur subbituminous coal and lignite. Although these types of coal yield less heat per ton than do either bituminous coal or anthracite, they compete successfully in the market place because of low per-unit production costs. Trends in coal production by rank are consist with the regional production shift; the share of subbituminous and lignite has increased from less than 5% to over 30% of production (figure IIIBii-5).

World coal production has also increased, although not at the same rate as has production in the U.S. Much of the increase has come in the far east, particularly P.R. China, whose output rose from 787 Mmst in 1983 to 1,226 Mmst by 1992. Australia, Columbia and South Africa also increased coal production in the 1980's.

Coal Exports

[72]Studies of the costs, health and safety issues, and environmental regulations associated with coal mining in Australia, Canada, Columbia, and South Africa were published by the USDI, Bureau of Mines, in 1989, 1988, 1986, and 1990 respectively.

The United States is a major coal exporter, shipping 99 Mmst to foreign customers in 1992 (figure IIIBii-6). Exports exceeded 100 Mmst in 1981, 1982, 1990 and 1991. Projected exports in the year 2000 are shown in table IIIBii-2. The EIA expects exports to reach 137 Mmst by that year. Exports of this magnitude may require increases in production, much of which could come from public lands in the western United States.

United States coal exports must compete in a global market place. EIA has tracked production for export by major coal producing nations and projected export supply out to 2010 (figure IIIBii-7). Their analysis suggests that the United States and Australia will significantly expand their production for export.

Coal Mining Productivity

Productivity, as measured by tons of coal produced per worker hour (T/Wh), is an important factor influencing the competitiveness of coal relative to other energy sources. Higher productivity results in higher production levels with the same amount of resources and in higher operator profits, allowing the firm to lower price in competitive markets without loss of profit margin. It can also serve as a justification for higher worker compensation per hour. Unfortunately, the coal industry has historically been plagued by low productivity levels compared to other sectors of the economy.

The issue of low productivity in the U.S. coal industry was investigated in the late 1970s and early 1980s by a number of authors. The following discussion will comment on two such studies: the U.S. General Accounting Office's (USGAO 1981) "Low Productivity in American Coal Mining: Causes and Cures" and a report by Oak Ridge National Laboratory (1979) which provided reference material to the GAO study entitled "Determinants of Coal Mine Labor Productivity Change." Unfortunately, the government has not recently reported on the rapid increase in coal worker productivity in both underground and surface mining during the 1980s.

Figure IIIBii-8 illustrates the trends in U.S. underground and surface coal mines from 1949 to 1990. Underground coal mine productivity increased steadily from 0.68 short tons per worker hour (T/Wh) in 1949 to 1.95 T/Wh in 1969. Over the period, productivity increased by 286.8 percent for an average of 14.3 percent per year. From 1969 to 1978 however, underground productivity decreased dramatically to 1.04 T/Wh or 53.3 percent of the 1969 level.

Average decline per year during this period was 5.2 percent. This was the lowest productivity rate since 1955. In 1978, productivity began to increase and by 1990 productivity reached a record 2.54 T/Wh. The average annual rate of productivity increase over the period was 20.4 percent.

The explanations for these period trends and turning points vary. Causes of productivity change fall into three general categories: Labor-management relations, mining technology, and the impact of Federal and state government regulations on mining operations and technologies. Underground mining is more influenced by labor-management relations than surface mining operations because of the relative labor intensity of underground mining operations. The GAO found the underground productivity decline during the 1970s was closely tied to the reduced quality of labor-management relations, particularly after 1973. The Federal Coal Mine Health and Safety Act of 1969 (MSHA) required additional labor for health and safety purposes and the 1974 union contract requirements calling for helpers on mine-face equipment increased labor-management problems. Additional younger, but better educated, workers were required for operations to meet the new manpower requirement. These workers both increased the number of workers per ton produced but also required training which further added to the decline in productivity. The requirements for helpers on face equipment contained in the 1974 wage agreement was estimated to account for a maximum 5% of the 13 percent decline in underground productivity during 1974-1975.

Whereas labor-management relations and MSHA were cited by GAO as having significant negative impacts on underground mine productivity, Federal and State reclamation laws were said to be largely responsible for the decline in surface productivity. The majority of the major surface coal producing states enacted or strengthened surface mining reclamation requirements after 1968. Moreover, states typically suffered a decline in productivity within 1 or 2 years of the enactment of the Surface Mining Control and Reclamation Act (1977).

Increases in productivity in the 1980s reflect a better working relationship between labor and management, an older and more experienced work force, a decrease in wildcat strikes, and an industry that has learned to work under MSHA and SMCRA regulations (Buckner 1994).

The type of technology employed by a coal mine significantly affects the level of worker productivity that can be achieved. The GAO study found that the greatest gains in underground mine productivity could be realized by improving reliability of coal cutting machines and improving haulage of mined coal from the face. Advances in machine maintenance

programs and haulage systems did not keep pace with productivity advances in coal cutting technology.

There has been a rapid increase in worker productivity at both underground and surface mines since 1978. Miner productivity at underground mines increased from 1.04T/Wh to 2.54T/Wh during the 1978 to 1990 time period, about 12%/yr increase. Much of the increase may have come from technological advances. During the 1977 to 1991 period continuous mining decreased from 64% to 58.9% of production, conventional mining techniques decreased from 25% to 11.4%, and longwall mining increased substantially from 5% to 29.3% of production. Given the GAO assessment of the productivity advantages of longwall mining, much of the recent productivity gain may be attributable to adoption of this technology.

Changes in surface mining productivity have been dramatic as well, increasing from 3.03T/Wh to 6.07T/Wh, or approximately 8%/yr over the 12 year period. The most probable explanation of these rapid increases is the significant increase in surface mining in the western United States, where seams are much thicker and overburden ratios are much lower. Between 1984 and 1991, surface mining production increased by 96,389 st/yr west of the Mississippi River but by only 3,764 st/yr to the east.

Coal Prices

The constant dollar price of coal sank throughout the 1950's and 1960's before rising dramatically in 1973 and 1974 in sympathy with the higher oil prices resulting from the Oil Embargo (table IIIBii-3). Since that time prices have dropped once again. There are several reasons for these decreases (USDOE, EIA 1992). Prices were bid up after the embargo and new capacity was installed (new mines developed) in anticipation of a rapid and widespread conversion to a coal-based economy that never materialized. The priced dropped in response to lower than expected demand and excess

[73]GAO reports overburden ratios of 10,4 to 28.0 in the Appalachian region, 8 to 25.7 in the midwestern region, and 2.1 to 6.7 in the western region.

(often high cost) capacity closed. In addition, an increasing proportion of production came from low-cost western mines. As figure IIIBii-9 illustrates, different ranks of coal face different prices in the marketplace. The constant dollar price/st of subbituminous coal, the type produced at large western mines, is half that of Appalachian bituminous coal, thus bringing down average U.S. coal prices. This combined with rising productivity has kept prices low.

Projected Supply and Demand

Coal is expected to remain an important fuel source into the next century. Demand will depend upon relative price, the state of technology, and advances in controlling the environmental effects of coal usage. Future supply will depend upon the discovery and development of replacement reserves, but EIA expects no long term capacity constraints, i.e., production is expected to meet domestic and export demand. Production and consumption forecasts from the DOE, National Energy Strategy (1992) are reported below. The basic assumptions of that model were reported in section IIIBiia and will not be repeated here. However, assumptions specific to coal are discussed below.

For the Base case, it has been assumed that there will be advances in coal technology based on steam injected gas turbines and advances in clean coal technologies. These latter could include pressurized fluidized bed boilers and integrated gasification combined-cycle generators. Both offer cost reductions, high efficiencies, and very low emissions of SO_2 amd NO_x. Productivity is assumed to increase by 1%/yr to 2000, and .5%/yr thereafter. Finally, coal exports are predicted to slow after 2015 as generation efficiencies and nuclear capacity increase around the world.

The Energy Strategy Case includes the same basic assumptions about coal supply and technology. However, because of alternative assumptions regarding increased use of nuclear generating capacity and advances in renewable technologies, the effects on coal consumption and production are noticeable.

Future Coal Consumption

Under the Base Case, coal consumption reaches 55 Q Btu by 2030 and 66.2 Q Btu by 2045, based on a trend extrapolation of DOE forecasts to 2030 (table IIIBii-4). In physical units this amounts to 2,581 Mmst by 2030 and 3,091

Mmst by 2045. Under the Energy Strategy Case consumption is projected to grow much more slowly, to only 32.3 Q Btu in 2030 and 34.4 Q Btu in 2045 (1526 Mmst in 2030 and 1630 Mmst in 2045).

Coal Reserves and Resources

The USDI, Geological Survey compiles comprehensive coal resource data in the United States. This information is then used by the Energy Information Administration (EIA) of the U.S. Department of Energy (USDOE) to report estimates of the various delineations of U.S. coal resources and reserves. Standard terminology is used in resource estimation. The definitions of these terms, and their diagrammatic representation in the McKelvey Box, were presented in Section IIB of this report and only delineations used by EIA in coal resource estimation are summarized here. Total resources are the sum of identified and undiscovered resources. Identified resources are the sum of the Measured, Indicated and Inferred categories. Demonstrated Reserve Based (DRB) is the sum of Measured and Indicated. Reserves refers exclusively to coal recoverable given known technology.

Domestic recoverable coal reserves (table IIIBii-5) total slightly less than 22 Bst. Given an average recovery rate of 70%, 15.4 Bst of coal could be made available to the market from coal reserves at existing mines, given current technology. Less than 100% of reserves are likely to be available because it is not always possible to mine the entire thickness of a seam due to technological or safety reasons. For example, pillars of coal might need to be left for roof support. The higher recovery percentages west of the Mississippi River are indicative of the thick, often uniform, surface minable coal seams found in that region. Recoverable reserves represent almost 15 years of consumption at current rates.

The U.S. demonstrated reserve base of coal was 475.6 Bst in 1992 (table IIIBii-6, of which approximately half is bituminous coal and another 37% is subbituminous coal. Slightly over half of the DRB is located west of the Mississippi River, with subbituminous coal predominant in the west and bituminous coal dominating in the east. As the EIA notes, approximately 50% of the DRB is "customarily" considered to be recoverable. Approximately 34% of the DRB is low sulfur coal, 31% medium sulfur, and the balance high sulfur (National Coal Association 1993).

[74]These are recoverable reserves at mines producing more than 10,000 st/yr as reported by mine operators to EIA.

Domestic and world coal resources are vast (table IIIBii-7). The USDOE, EIA 1993d reports U.S. resources as slightly less than 4 trillion st. Another source estimates U.S. coal resources at 2.9 trillion st, of which 182 Bst are deemed reserves in place that can eventually be recovered (World Energy Conference, quoted in Feltweis 1979). This latter reference also states that both the former Soviet Union and P.R. China hold large coal resources and that overall world coal resources were in excess of 10 trillion st in 1974.

Future Coal Production

USDOE (1992) estimates of coal production through 2030 (with trend extrapolations through 2045) are reported in table IIIBii-4 in energy and physical units. Under both scenarios, production is expected to increase,; however, the rate of increase differs dramatically between the two cases. Under Base Case assumptions production grows from 1,051 MMst in 1995 (projected) to 2,854 MMst by 2030, and 3,368 MMst by 2045. The Energy Strategy Case incorporates assumptions that reduce consumption of coal. As a result, production is forecast to reach only 1,798 MMst by 2030, and 1,906 MMst by 2045.

Projected Supply and Demand Balance

Production is forecast by DOE to exceed domestic consumption through 2030 (and through 2045 by trend extrapolation.) As is clear from the resource and reserve estimates reported above, the United States has more than adequate supplies of coal to support these projected levels of production and consumption. As a result, the U. S. is expected to remain a net exporter of coal into the next century, and in fact is projected by USDOE, EIA 1991 to increase exports substantially (figure IIIBii-7).

Under the Base Case assumptions, the price of coal is expected to rise to $27.53/st 2030 and to $32.17/st by 2045 (based on trend extrapolation, both prices in 1982 $s). The represents approximately a doubling of prices between 1993 and 2030 (on a constant dollar basis). If consumption does not increase at the rate projected in the Base Case, but rather at the slower rate assumed in the Energy Strategy Case, the price of coal reaches $25.47/st by 2030, and $29.02/st

by 2045 (1982 $s).

Solid Hydrocarbon Issues

Coal extraction has the potential to create undesireable environmental impacts. While environmentally sound mining practice is the norm today, acid mine drainage from abandoned or unreclaimed mines, as well as subsidence, remain as problems. The types of impacts and appropriate mitigating measures were addressed in sections IIE and IIF, covering technology and environmental impacts respectively.

Eastern coal resources are extensive; however, coal recoverability has become as issue in some areas. Typically, 80% of the coal is recovered at open cast mines, and 50% from underground mines. The remainder is lost in waste materials, left in place to provide support or prevent subsidence, or cannot be mined profitably due to its physical characteristics or location. Recently revised estimates place recoverability as low as 30% for some undergournd mining districts in the east. As a result, minable coal resource in those areas may be depleted sooner than was previously expected (in some cases within 50 years.) For rural communities heavily dependent upon coal mining for jobs and income, depletion will have significant negative economic and social impacts.

Many National Forests in the eastern United States are underlain with privately held nonrenewable resources. There are specific rules and regulations to ensure that owners have access to their property. With respect to coal, the Surface Mining Control and Reclamation Act (1977) requires that a person wishing to develop coal on NFS lands in the eastern United States, establish a VER (either Reserved or Outstanding) through the Office of Surface Mining (OSM). Prior to processing VER requests to the OSM, the Forest Service is asked to give an opinion as to whether or not the deed conveyed the right to mine coal by surface methods. If the Forest Service opinion states that the such a right is not conveyed by the deed, the OSM will not process the request. In those cases where the Forest Service opinion states that the deed does convey such a right, the OSM processes the VER request and the mineral owner may develop the resources once the appropriate permits are obtained. It is Forest Service policy to cooperate with the mineral owner once a VER is established and permits are obtained. However, the agency does expect operations to be reasonable and environmentally acceptable. During the permitting stage, if the Forest Service finds that operations would not be environmentally

acceptable or could not be adequately mitigated, the agency will not allow the operation to occur. In such rare case, the Forest Service may consider acquisition of the mineral estate.

ENERGY AND MINERAL PRODUCTION FROM FEDERAL LANDS

FEDERAL LANDS

Federal lands, including the National Forest System (NFS), are underlain with extensive energy and mineral resources. Regulation of access, development and production activities varies depending upon the resource and land ownership status, as discussed in Section IIB. All energy resources are leasable, i.e., regulated under the Mineral Leasing Act of 1920 as Amended, so royalties must be paid and production levels reported. No royalties are collected on locatable minerals, those falling under the purview of the Mining Law of 1872. However, non-energy resources may be either be leasable or locatable depending upon whether the land is Public Domain or Acquired. The production and royalty data provided by MMS for non-energy minerals reflects only the output from leases, not total output from Federal lands.

Crude oil production from on- and offshore Federally administered lands peaked in 1985 and has since declined to below 1977 levels, a scenario consistent with the exploration and development statistics reported in Section IIEii (table IVA-1). Overall Federal production has consistently represented between 16% and 20% of domestic production. Federal production accounted for almost 12% of U.S. consumption (in Btu terms) in 1985, but represented only 9% of consumption by 1992.

Natural gas production on- and offshore from Federally administered lands increased by 26% between 1977 and 1992, reaching 6.25 Tcf in that year (table IVA-2). Federal gas production consistently accounts for between 25% and 35% of domestic gas production, and only slightly less of consumption.

The increase reflects the fact that deregulation has made gas production more profitable than was the case in 1977, as have tax incentives for tight sands gas. Heightened use of natural gas due to its clean burning properties will probably lead to continued and possibly expanded interest in gas resources on pubic lands.

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[75]Estimating locatable mineral production levels for public lands is not a straight-forward process. Firms are not required to report production to the Federal government. Moreover, the mine may encompass both patented and unpatented tracts making categorization of production as Federal or private is extremely difficult. The USDI, Bureau of Mines, solicits production information, but data are seldom reported to them organized by individual mine, and almost never by land ownership status.

[76]Oil production from onshore leases totaled 126.7 MM bbls in 1993; gas production was 1.7 Bcf.

Coal production from Federal lands has increased dramatically in recent years (table IVA-3). As of 1977, coal from Federal lands represented 11% of domestic coal production and 11% of coal consumption (in Btu terms). By 1992, coal from these lands had increased its share to 27% of production and 30% of consumption (in Btu terms).

Much of the Federal coal output has been from large western open pit mines producing low sulfur, subbituminous coal. Wyoming, in particular, has seen a large increase in production, centered in the Powder River Basin. Given continuing concerns about air quality and regulation of emissions from power generating plants, demand for low sulfur coal is expected to remain strong.

NATIONAL FOREST SYSTEM LANDS

NFS lands are the repositories of extensive energy and non-energy resources. Of the 191 million acres in the NFS, 6.5 million are underlain with coal, 45 million acres have oil and gas potential, and 300,000 acres have phosphate potential (USDA, FS 1985). A wide variety of resources are present on public lands. For example, some forests have high quality deposits of decorative stone, others have pumice, gem stones, base or precious metals. Geologically, the National Forests (NF's) contain some of the most favorable host rocks for mineral deposits. Information on mineral potential, provided by the USDI, Geological Survey and Bureau of Mines, is being included in Forest Plan revisions so that land managers and the public can plan for the eventual utilization of these resources. As of 1992, there were 12,700 mineral operations on NFS lands. By 1993, this number had dropped to 10,700 and is expected to continue to decline in the next century (10,100 in 2000, 9,400 in 2005 and 2010). Tables IVB-1 through IVB-9 show historic and projected NFS production for 3 energy resources, and 6 minerals, each of which have been designated as indicators of mineral activity of NFS lands. These tables are discussed below. In addition, each of these resources is discussed in depth in section IIIA (for minerals) and IIIB (for energy resources). Commodity specific issues are addressed in the individual commodity chapters.

Although the level of petroleum exploration and production has varied from year to year based on market conditions, there has been sustained production of oil or gas from NFS lands for many years. NFS lands are also important for what they can potentially produce. Much of the less explored areas in the lower 48 states lie within NF's,

including large portions of both the eastern and western thrust belts. There were over 11,000 leases on 109 of the 156 NF's, with producing wells on 26 Forests in the early 1990's; however, 71 of the NF's have never had a single exploratory well drilled.

Petroleum production from NFS lands has decreased since the mid-1980's, but is forecast to increase substantially in 2000 and beyond (table IVB-1). NFS production has represented less than 1% of historic domestic production and consumption, and based on DOE (1992) forecasts of the petroleum market, is expected to remain a relatively small percent of domestic output and use. Gas production from NFS lands is also forecast to increase from historic levels (table IVB-2). If this expansion occurs, NFS production would represent approximately 2% of domestic production and consumption by 2045[3].

In 1992, there were 113 coal leases covering 207,823 acres on NFS lands. By 1994 this number had dropped slightly to 110 leases for 196,517 acres (IVB-3). Production of coal from Federal leases on NFS lands has more than doubled since the mid-1980's and by 1993 represented almost 10% of domestic production and 12% of consumption. Although production from NFS lands is forecast to increase, its share of domestic production and consumption is expected to decrease, based on DOE (1992) coal production and consumption forecasts[3].

Copper production from NFS lands has decreased since the mid-1980's, but is forecast to increase again in the 2000 and beyond (table IVB-4). In 1986 NFS production accounted for 6.4% of total U.S. output and 4% of consumption; by 1993 the percentages had slipped to 1% of production and .7% of consumption. However, copper mines may be developed on NF's in Montana and Arizona and perhaps in Wisconsin as well. While output is not expected to reach the levels seen in 1987 or 1988, it would represent over 2% of domestic consumption (based on consumption forecasts provided by the USDI, Bureau of Mines.)

Gold output on NFS lands has been increasing, from 564 M troy oz to over 1000 M troy oz by 1993 (table IVB-5). Because gold production in the U.S. is booming, this expanded NFS output accounted for a decreasing percent of the U.S. total. These twin trends are expected to continue. Although NFS output fulfilled 37% of non-financial U.S. demand in 1993, it is expected to represent only 22% by 2010, and 12.5% by 2045 (based on consumption forecasts provided by the USDI, Bureau of Mines).

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[77]Base Case scenario. Assumptions for the Base Case are discussed in detail in Section IIIBi.

A significant, though decreasing, proportion of the domestically mined lead comes from NFS lands (table IVB-6). Much of this output has been from the Mark Twain NF in Missouri. In 1986, fully 63% of production (223,445 mt) and 19.5% of consumption originated on the NFS. By 1993, production had declined to 131,961 mt, which accounted for 36.5% of production and 9.5% of consumption. The USDI, Bureau of Mines has predicted that lead consumption will increase in the next century. At the same time, lead production from NFS lands is predicted to decline to only 14,062 mt by 2045.

NFS lands in Colorado, New Mexico, and Idaho are the source of a large proportion of the molybdenum produced and used in the United States (table IVB-7). In 1993, 66% of domestic production and 150% of consumption were from these sources. Molybdenum output from NFS lands is predicted to increase steadily through 2045. Much of this increase would come from a world class deposit in Alaska. The increased output would represent a decreasing percentage of U.S. consumption as use is predicted to rise at an even higher rate than is output. Nonetheless, predicted production from NFS lands would be more than twice predicted domestic consumption through 2045.

The United States is a major world producer and exporter of phosphate rock. Deposits in Florida, North Carolina, Idaho, Montana, Tennessee and Utah ensure a secure domestic supply. As of 1993, 14% of domestic production and 13% of consumption came from NFS lands (table IVB-8). Output levels are predicted to remain largely unchanged, but share of consumption is forecast to rise slightly as overall usage of phosphate declines are the turn of the century (based on consumption forecast from the USDI, Bureau of Mines.

Sand and gravel (construction grade) is produced in every state in the Union and on most NF's. The materials are sold under the Mineral Materials Act (1947), donated to local governments or school districts, or used internally for road construction. Production of sand and gravel from NFS lands has consistently amounted to between 2% and 4% of domestic production and consumption (table IVB-9). U.S. consumption is predicted to rise slightly between 2000 and 2045 (USDI, Bureau of Mines forecast) and NFS output is predicted to keep pace.

ENERGY AND MINERALS ISSUES

There are many important issues associated with energy and mineral production and consumption in the United States. We focus here on two, the impact of extraction on rural communities, and the distribution of abandoned and inactives mines.

ECONOMIC IMPORTANCE OF THE MINERALS INDUSTRY TO LOCAL ECONOMIES

Although mining comprises only 0.9 percent of U.S. nonfarm labor income (Bureau of Economic Analysis, 1993), the industry can take on a much greater significance at the local level. Because mineral deposits often occur in isolated and sparsely populated places, mining may account for a very large share of a local economy's employment and income. The impacts of mineral activities and the relative importance of the mining industry depend upon such factors as the type, scale, intensity, and duration of the operations, as well as the characteristics of the local economy (Wenner, 1992). These factors also determine the magnitude of effects on sectors that supply inputs to the mineral operation (indirect impacts) and the employment and income changes resulting from employees and business owners spending their income in the area (induced impacts).

Short-term exploration projects may have relatively little effect on the area's economy. Few, if any, local residents may be hired, and goods and services required to conduct the exploration may be obtained largely from outside the area. A portion of an employee's income would be spent locally (e.g., for food, lodging), but a greater share would be "exported" to the worker's primary place of residence.

Large-scale mineral operations of long duration may, on the other hand, have a pronounced impact on an area's economy. The local population would become a more important source of labor for the operation, but jobs would also be filled by nonresidents who permanently move to the area. Goods and services needed for the minerals project may be obtained locally, either from existing or newly established businesses. A higher percentage of a worker's personal consumption expenditures would occur in the local community, leading to an expansion of jobs and income in such sectors as retail trade and services. Thus, the multiplier effect, which takes into acccount the indirect and induced impacts, as

well as the direct effects, would tend to be much larger than for a short-term operation of limited scale.

Economic diversity and dependency analysis can be used to provide some indication of the importance of mineral activities to an area. Economic diversity relates to the number of sectors in an area and how employment and income are distributed among those sectors (DeVilbiss, 1992). Economic diversity can be expressed by simply calculating each industry's percentage share of total employment or income. Taken further, these percentages can then be used to compute an economic diversity index for the local economy.

Economic dependency analysis is based upon the idea that those industries that produce goods and services locally but sell them elsewhere are the sectors that determine the growth patterns of a regional economy. Thus, economy dependency focuses on exports from the area. The larger the percentage of total exports in a given sector, the more the economy is dependent upon that sector. In contrast to economic diversity analysis, where the emphasis is on direct impacts, an economic dependency evaluation also considers the indirect and induced effects of producing at a certain output level.

For a diverse local economy, an contraction in one industry may very well be offset by an expansion in another (and vice versa), thus smoothing out employment and income fluctuations. Excessive dependency on a single sector, however, can subject a local economy to severe disruptions. The same multiplier effects that occur when an existing industry expands or a new business moves into an area also come into play in the opposite direction. Businesses that provide inputs to the industry whose output is reduced are also affected, as are establishments where employees spend their income.

Mining is sometimes viewed as an undesirable addition to a local economy because of the "boom and bust" nature of the industry. Even at the national level, the notion that income or employment in mining may not be as stable as other industries has validity. U.S. labor income from mining totalled $32.2 billion in 1991 (Bureau of Economic Analysis, 1993). Over the period 20-year period from 1971-1991, mining labor income grew at an average annual rate of 7.9 percent, somewhat below the growth rate in total nonfarm labor income. Dividing the 20-year period into 5-year segments shows that changes in mining labor income have been far more erratic than in other Standard Industrial Classification (SIC) divisions.

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[78]To facilitate the collection and comparison of establishment-based economic statistics, the Office of Management

The decade of the 1970s was one of rapid growth in mining income. High commodity prices led to a significant increase in exploration and development activity, causing employment and income to rise. With the decline in metal and oil and gas prices in the early 1980s, activity levels plunged, many producing mines closed or substantially reduced the size of their workforce, and oil and gas wells were shut in. As a result, mining labor income decreased an average of 6.9 percent per year from 1981-1986. During the most recent 5-year period, mining labor income expanded at a rather anemic rate of 1.5 percent annually. Mining remains one of the highest paying sectors in the U.S. economy, however, ranking first among major nonfarm private industries with average earnings of $14.59 per hour (Bureau of Labor Statistics, September 1993)

The effects of fluctuations in employment or income in the mining industry nationally can be magnified at the local level. As discussed previously, how well an area can cope with such changes depends not only upon the scope of the mineral activities, but also upon the makeup of the local economy. In the case of new or expanding mineral operations, communities with larger populations generally already provide a wide range of services and facilities and are more likely to have workers available with necessary skills. Such communities are, therefore, better able to accomodate changes that may result from the mineral activities.

An identical level of minerals activity can pose considerable difficulties for smaller communities. A rapid population increase strains the ability of these communities to provide such services and facilities as schools, law enforcement, medical and emergency services, housing, and social services. Even when additional tax revenue is generated from the minerals operation, there is often a lag between the demand for facilities and services and the receipt of the taxes.

If highly dependent upon a single industry, large cities are not necessarily immune from the effects of output fluctuations in that sector at the national level. For example, after oil prices dropped in 1986, industry spending on exploration and development plummeted. Cities such as Houston and Denver, as well as many small towns, were

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and Budget of the Executive Office of the President maintains the Standard Industrial Classification. The classification covers all economic activities, and codes are assigned to each establishment based upon the principal products produced or distributed or the primary services rendered. The coding system detail ranges from broad divisions (e.g., Division B, Mining) to much more specific four-digit industries (e.g., Industry 1041, Gold Ores).

adversely affected by the decline in oil and gas activity. Losing their jobs, many industry workers moved away seeking better employment opportunities, which resulted in reduced consumer spending in the area. Consequently, local businesse sales decreased. Tax revenue also fell, leaving communities with more and larger facilities than they needed and a reduced ability to provide services. Schools had surplus capacity, and housing vacancy rates shot up, severely depressing housing values. Unemployment rates also escalated.

There are communities, large and small, throughout the United States that rely heavily on a single industry to generate employment and income. Local economies that are currently or potentially dependent upon mining are sometimes able to exert a certain degree of control over the socioeconomic effects of mineral activities. The Stillwater Mine, the only producer of platinum and palladium in the United States, provides but one example of how important mineral activities are to a rural economy and how the potential socioeconomic impacts of a major mine development can be mitigated.

Stillwater Mine

The Stillwater Mine, which began production in 1987, is located in Stillwater County, Montana, near the town of Nye. Although some facilities are on private land, a portion of the project area is on federal land administered by the Forest Service. The Forest Service and the Montana Department of State Lands prepared an environmental impact statement which disclosed the potential effects of mine development and alternatives to the proposed action. Subsequently, both agencies approved Stillwater Mining Company's plan of operations contingent upon the implementation of a number of measures designed to mitigate adverse environmental consequences.

According to Bureau of the Census estimates, the population of Stillwater County was 6536 in 1990, a 16.8 percent increase over the 1980 figure of 5598 (Montana Department of State Lands et al., 1992). The rate of population growth in Stillwater County in the 1980s exceeded that for both Montana and the United States, and the development of the mine was clearly a major factor in the increase.

Hiring at the mine reduced Stillwater County unemployment, and over the 1988-1990 period, the jobless rate in

the county was below comparable figures for the U.S. and Montana. The Stillwater County unemployment rate jumped in March 1991, as the mine laid off about one-fourth of its workers to reduce costs. By 1992 the unemployment rate had once again fallen below the Montana and U.S. rates, probably due to a combination of outmigration and the withdrawal of discouraged job seekers from the labor force.

The opening of the mine positively influenced per capita income, a measure of economic well-being. Per capita income in Stillwater County was $16,111 in 1991, compared to $19,091 for the U.S. and $15,680 for Montana (Bureau of Economic Analysis, 1993). In constant dollar terms, per capita income in the early to mid-1970s was relatively equal among the United States, Montana, and Stillwater County. For about the next 10 years, per capita income in the U.S. continued to rise while remaining flat in Montana and Stillwater County. With the opening of the mine, Stillwater County's per capita income rose above the state's and until the layoffs occurred, the gap between the U.S. per capita income and that of Stillwater County had been narrowing.

The start-up of the Stillwater Mine also seems to have contributed to the diversity of the local economy. In 1985, prior to the initiation of production, the agriculture, forestry, and fisheries sector accounted for the highest share of employment, 22.6 percent, followed closely by services (figure Vi-1). The distribution of total income in the county differed significantly from the employment percentages shown in figure Vi-1, reflecting the wide variation in industry wage rates. The government sector was the largest source of income in 1985, making up 28.6 percent of the total (figure Vi-2).

The biggest change in the Stillwater County economy over the 1985-1990 period was the addition of the mining sector. By 1990, mining accounted for 10.4 percent of county employment and 31.9 percent of income. Compared to employment, the changes in the distribution of income were more severe. The trade; fire, insurance, and real estate; services; and government sectors experienced a significant reduction in their shares of total income.

Using employment data for various years, the Forest Service (1993) has computed economic diversity indices for

Stillwater County and all other U.S. counties. The indices have been normalized to range between 0 and 1. An index of 0 indicates that all economic activity is concentrated in just one industry and there is no diversity, while an index of 1 means every industry's share of total employment is equal. Indices were computed at the one-digit (i.e., division), two-digit, and four-digit SIC code levels. As might be expected, the economic diversity index increases at higher levels of industry aggregation. The indices at a particular SIC aggregation level have generally been rising over time, indicating that U.S. counties are becoming more diverse.

With an economic diversity index of 0.8161 (1-digit SIC level), Stillwater County ranked thirty-second of the 56 Montana counties in 1990. In 1985, before the mine was in production, Stillwater County's diversity index ranked fortieth in the state. Only four Montana counties experienced a greater increase in the economic diversity index over the 1985-1990 period.

Although the Stillwater County economy seems to have become more diverse with the opening of the mine, an economic dependency analysis, which takes all impacts into account (i.e., direct, indirect, and induced), shows how dominant mining is in the economy. This dominance is particularly evident in terms of income. In 1990, 20.3 percent of Stillwater County's export-related employment and 43.0 percent of export-related income were attributable to mining (figures Vi-3 and Vi-4). Platinum and palladium concentrates produced at the Stillwater Mine are shipped to the company's Columbus smelter, which is also located in Stillwater County. The smelter output is then exported from the county for further processing.

The transition of the Stillwater County economy could have been much more disruptive had certain actions not been taken prior to the development of the mine. In some states, including Montana, mining operators are required to negotiate with affected local jurisdictions on ways to mitigate adverse socioeconomic impacts. In the case of the Stillwater Mine, the company agreed to provide mitigation in the form of tax prepayments, grants, and guarantees for the payment of principal and interest on educational impact bonds. Outside the framework of this Hard Rock Mining

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79 Install Equation Editor and double-click here to view equation.

The economic diversity indices were calculated using Shannon's entropy function:
where E_i is the percentage of total employment in industry, i, and n is the number of industries in the region.
Since the index rises as the number of industries increases, the indices were normalized by dividing the computed index by the maximum possible index achieved when each industry's share of total employment is equal.

Economic Impact Plan, the company helped ease the housing shortage by guaranteeing loans for employees to purchase mobile homes and making mobile home spaces available to them. Stillwater Mining Company also developed a subdivision for permanent housing and offered lots at below cost to workers.

Economic and social impact mitigation measures for the Stillwater Mine are not confined to problems associated with rapid growth. Montana collects a metal mines license tax on production from the mine, and a portion of the proceeds are returned to Stillwater County. A certain percentage of these funds are then held in reserve until the mine shuts down or there is a substantial workforce reduction. The reserve funds can then be used for such purposes as providing grants or loans to municipalities, retiring debt, initiating economic development efforts, aiding schools, and offering property tax relief.

Mitigation measures, such as those designed for the Stillwater Mine, can never totally eliminate the difficulties communities might face by being highly dependent upon a single industry. Well-planned mitigation of economic and social impacts can, nevertheless, bring many problems down to a manageable level.

DISTRIBUTION OF ABANDONED AND INACTIVE MINES ON NATIONAL FOREST SYSTEM LANDS

Mining in the United States has a rich and colorful history. Domestic mineral production has facilitated economic growth, while providing many interesting tales of courage, hardship, and wealth creation. Unfortunately, the industry has left another, less desirable legacy - abandoned mines. Prior to the 1970's, reclamation of mine sites was not required and consequently not performed for the majority of sites. Abandoned mines were often simply ignored. Although they may be of historical interest, abandoned mines are also creating current problems. Unreclaimed sites often detract aesthetically from the landscape or pose physical hazards that could subject the unsuspecting explorer to risk of personal injury. Moreover, we now know that both surface and underground mines, as well as mill and smelter wastes, can discharge toxic materials that degrade water quality and that runoff from unrevegetated spoils piles causes increased stream sedimentation.

An assessment of the distribution of abandoned and inactive mines has been conducted (Shields et al 1995). It is based on the nonconfidential portions of the Mineral Availability System (MASNP) database that has been compiled by

the USDI, Bureau of Mines (BOM.) Information on type of activity (e.g., underground versus surface mining), status (e.g., current versus past producers), mineral commodity extracted, and land ownershi, are provided for each mineral location.

The BOM has identified 89,720 past producers in the United States. Of these, 53 % were surface mines, another 37 % were underground or combined operations, and 4 % placer (table Vii-1.) Among current producers there is a much greater preponderance of surface operations (77 %) and fewer placer mines. These changes reflect a shift toward solution mining techniques and away from more expensive or perhaps more environmentally damaging mining methods of the past.

BOM estimates of land ownership are only approximate, as title to land can and frequently does change hands. The entries represent ownership at the time the site was recorded in the database and are not normally updated by the BOM. This is important to bear in mind when reviewing data for minerals on public lands. Mineralized land has been and continues to be transferred to the private sector under the Mining Law of 1872. This law regulates exploration, claim staking and production of metallic and some nonmetallic minerals from public domain lands, those which have never left the Federal estate. If a US citizen or firm can show that a claim site contains an economically viable deposit, it may be taken to patent, a process by which title to the surface and subsurface is permanently transferred to the private sector. Over the past 122 years thousands of mineral locations that were once publicly held have been transferred to private ownership in this manner.

Many abandoned and inactive mines in the western United States can be found on claims that were taken to patent in the late 1800 and early 1900's. Often these claims lie within what are now the contiguous boundaries of NFS, BLM or other Federal lands. In some cases, the current private owners are unknown or difficult to locate. Nonetheless, Federal employees may not enter these privately held sites to ascertain the status of mine workings or evaluate potential physical hazards to individuals or environmental risks to adjacent public lands or waters without permission of the landowner. All Federal agencies are in the process of inventorying the abandoned and inactive mines on their lands; however, mineral inholdings will not be included in these totals.

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[80] There is limited information on coal and uranium mines, and virtually no information on crude oil or natural gas in the BOM database.

[81] Extraction of energy resources and some industrial minerals, as well as mining of all resources on acquired lands, is regulated under the Mineral Leasing Act of 1920 (as Amended.)

Nonetheless, any mine on or within the NFS has the potential to create water quality problems. To provide an estimate of the magnitude of the potential problems active, abandoned and inactive mines pose for NFS lands, mineral locations have been sorted by latitude and longitude. Any site falling within the administrative boundaries of NFS lands is assigned to the NFS ownership category. All other sites are assigned to either Federal Other Than BLM or All Other Including BLM. This information has been combined with data of type of activity in Table Vii-2.

When the data are sorted in this manner almost 39,000 (approximately 19 %) of all mineral locations occur within the administrative boundaries of NFS lands, an increase from the 13 % occurring on NFS lands according to the BOM designations. Of these, 15,114 are identified as underground or surface/underground mines, 8883 as surface and 3,348 as placer mines. In comparison with other two ownership categories, a greater proportion of mines on NFS lands tend to be underground and fewer surface.

Approximately 13,70 of the past producing mineral locations in the United States lie within the boundaries of the NFS (figure Vii-1.) It is clear that while Forests in all parts of the country are impacted, some areas have seen more historic mining activity than have others. National Forests located in areas that have experienced past mineral activity are more likely to have past producers within their boundaries.

Table Vii-3 lists the frequency of occurrence of past producers within NFS boundaries for selected commodities. The preponderance of underground mining operations is clear. Over 50 % of past producing sites within NFS boundaries are underground or combined surface/underground operations. This is consistent with the percentages for mineral activities on NFS overall and is not unexpected given that underground mining is common in mountainous areas of the western United States where the agency administers large tracts of land. In addition, a disproportionate 37 % of the placer operations took place at locations within what are now NFS boundaries.

Not all abandoned mines are equally problematic in terms of their potential risk to water or general environmental quality. For example, the vast majority of sand and gravel mines are relatively benign, although they can create sedimentation or visual problems. Other commodities or ore types can cause graver problems, on the most significant of which is acid mine drainage.

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[82] BLM data are not reported separately because BLM boundaries have not been digitized. For this same reason they could not be included in the Other Federal category.

Both surface and underground mines can be affected by acid mine drainage. In underground mines the water table is typically lowered during operation. Sulfide rich strata are exposed to air, triggering acid forming reactions. Once mining is complete, the water table may rise, bringing water into contact with the oxidized sulfides. Acid mine drainage problems are exacerbated when the low Ph waters come in contact with mineralized zones and dissolve heavy metals, many of which are toxic to aquatic life. The process is similar in open pit mines; after mining ceases, the excavated area fills with water and leaching from the surround rock occurs.

In the eastern United States, most acid mine drainage is the result of past coal mining operations. In the western parts of the country, acid drainage flows from abandoned and inactive underground and surface metal mines. Estimates of the number of western mines affected by acid drainage range from 20,000 to 50,000 or more. Over 1,500 sites with significant acid mine drainage problems have already been identified on NFS lands.

Of the minerals listed in Table Vii-3, some are of more concern to water quality than others. Among metals, arsenic, cadmium, copper, lead, mercury, and zinc, have significant potential to cause water quality problems. These have been labeled Minerals of Concern. The level, if any, of environmental problem created by the presence of one of these minerals is a function of acidity, moisture, background geology and a host of other factors. Nonetheless, their presence warrants heightened awareness and oversight.

Currently, responsibility for abandoned mines is shared among Federal and State governments and private land owners. Typically, private land owners are responsible for safeguarding hazards on their property. State inactive mine programs assist owners with the closure of mine openings using Title IV funds collected under authority of the Surface Mining Control and Reclamation Act of 1977 (SMCRA.) This Act, due to expire in 1995, required surface-mined coal operators to pay a quarterly fee to the Abandoned Mine Reclamation Fund. (The Energy Policy Act of 1992 extends the requirement for payment of these Title IV funds through 2004.)

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[83] See Mining and Water Quality: Potential Water Contaminants by T. McNulty and D Shields and Mining and Water Quality: Toxicity of Potential Water Contaminants by S. Wright and D. Shields, both forthcoming.

OPPORTUNITIES FOR IMPROVED MANAGEMENT

In the past, energy and minerals activities were often viewed by public land managers as beyond their control. This attitude stemmed from the fact that the laws regulating nonrenewable resources preceded, and in many cases continue to supersede, both the Multiple Use Sustained Yield Act (1960) and the National Forest Management Act (1976). The latitude public land managers have in controlling energy and mineral development depends upon both land status (public domain, private ownership, unpatented mining claims, split estate, etc.) and the resource in question (metals, energy resources, common variety minerals, etc.). In some cases, approval of a new operation is at the limited discretion of the manager. In others, the agency has only limited amounts of control over either the approval process or the plan of operations. Nonetheless, many land managers now recognize that it is possible to incorporate energy and minerals activities into planning in ways that benefit both the public and the industry. We focus here on those opportunities for improved management which emphasize the integration of non-renewable resources into long term planning and ongoing management.

Information on background geology should be an integral component of the overall land planning process. Some, though not all, Forest plans now include this type of information, but it is seldom used to its full potential. An ongoing geology program can provide geochemical and land stability interpretations for ecosystem restoration and improvement projects, identify geologic conditions that may affect health and safety, and contribute to the cost-effective design, construction, and maintenance of the NFS infrastructure. Moreover, there is a close relationship between the type of ecosystem occurring at a site and the nature and structure of the subsurface materials. Access to geologic information will enhance both understanding and management of ecosystems.

It is also essential that energy and mineral resource and deposit information be made available to land managers and considered in the planning process. It is the policy of the Forest Service (1995) to: "Foster and encourage private enterprise in the development of economically sound and stable industries, and in the orderly and economic development of domestic resources to help assure satisfaction of industrial, security, and environmental needs." National Forests and Grasslands are viewed by the agency as playing an "essential role" in fulfilling our needs for nonrenewable resources.

This policy of supporting and fostering stable and sound mineral development can better be accomplished when

managers have access to accurate information that identifies claims, deposits, and areas of high mineral potential. Where economic deposits have been identified, but remain in the Federal estate, interest in their development will depend upon market forces. Access to these types of data would help land managers to coordinate multiple use activities with energy and mineral extraction. It may be appropriate to designate, to the degree possible, those areas where mineral developments will and will not be approved. This would benefit industry by reducing uncertainty. They could focus their exploration efforts on areas where they could expect development approval were a discovery to be made and restrict activity in those areas where development had been deemed inappropriate, thus better utilizing their scarce resources and capital.

Incorporating minerals information into the planning process can also prevent future conflicts. For example, where commodity deposits are privately held, access may need to be accommodated in the future; the land over the deposits should not be designated as roadless. An area with high potential for resource development, one containing numerous patented and unpatented metallic mineral claims, might appropriately be managed for wildlife habitat, but not for long term use as a municipal watershed. Land underlain by a high grade coal deposit is probably not the best location for a permanent visitor center, at least until after mining and reclamation. Conversely, mineral extraction might not be desirable on land with other significant biological, historical, or cultural resources. Foreknowledge of the mineralogy would allow time for reasoned debate and consensus as to the best use for the site.

This type of coordinated resource planning requires knowledge of the level of resource commitment associated with a mineral development, i.e., the period of time that other resource outputs must be reduced or altered to accommodate production of the nonrenewable resource in question. There are four basic levels of resource commitment:

Type	Example
- short term incompatibility	- heavy road use during elk calving season
- partial compatibility	- oil production in an area with ongoing forage, wildlife, and recreation usage
- long term commitment	- surface coal mining on the high plains, followed by reclamation
- permanent commitment	- a large open pit metal mine in

an arid environment

Exploration and small scale development activities usually fall within the first two categories. Often these activities tend to be of short duration and the sites where they occur are fully reclaimable. In other cases, the health of the ecosystem or quality of a recreational experience impacted, but not permanently damaged or eliminated. Conversely, the presence of a large mineral operation usually precludes other multiple use activities, at least until after reclamation. And of course, there are instances where land dedicated to mining is unlikely to be available for other uses in the foreseeable future. Knowledge of the expected longevity and intensity of the mineral activity should be part of long range planning for each Forest.

The Forest Service is committed to the principles of ecosystem management, one aim of which is to "take care of the land by continuing to restore and sustain the integrity of its soils, air, waters, biological diversity, and ecological processes" (Bartuska 1993). Due to the nature of energy and mineral production, the process of exploring for, developing, and extracting oil, gas, and other energy and mineral commodities can have a number of short- and long-term effects on a region's environmental attributes as was discussed in section B.V. of this report. Many of these impacts can be prevented or mitigated, as was discussed in section B.IV of this report.

For energy and mineral resources to be effectively incorporated into the ecosystem management paradigm, their presence and the likelihood of development will need to be considered throughout the planning process. When they are handled as integral parts of the planning process, it is possible to identify resource management goals that would benefit from mineral development. For example, site reclamation could be designed so as to provide watering sites for wildlife, reseeding could be viewed as an opportunity to alter species mix, or waste rock could be used for road maintenance.

The Mining Law of 1872 and the Mineral Leasing Act of 1920 explicitly permit exploration for private ownership and extraction of energy and mineral resources from the public lands. These laws have been and continue to be controversial. What ever the outcome of the current debate over energy and mineral development on public lands, valid private mineral rights, outstanding claims, patented inholdings, mineral leases and contracts, and the thousands of abandoned mines will continue to exist on the NFS. Technically skilled oversight of these mineral locations will be necessary if high public expectations regarding the ecologically sound management of public lands are to be met.

VII. REFERENCES

Adelman, M.A. 1993. The economics of petroleum supply. MIT Press, Cambridge. 528 p.

Alaska State Legislature. 1989. Memorandum from Gretchen Keiser, Legislative Analyst to Representative Fran Ulmer. Regulation of mining developments and the management of socioeconomic impacts. Research Request 89.395. 15 p.

American Petroleum Institute. June 1984. Compatibility of oil and gas operations on federal onshore lands with environmental and rural community values. Discussion Paper #033. 100 p.

Banister, D.P.; Barnes, D.J.; Longwill, W.D. 1984. Availability of federally owned minerals for exploration and development in western states: Washington. Washington Department of Natural Resources Publication No. GM30. 17 p.

Bauer, A.M. 1991a. Mineral resources management programs and the construction aggregate industry. Planning and Zoning News. Lansing, MI: Planning and Zoning Center, Inc.: 5-10.

Bauer, A.M. 1991b. Reclamation opportunities. Chicago, IL: Pit & Quarry Publications: 84: 40-41.

Beach, R. A.;Gray, Arthur W.;Peterson, Eileen K.;Roberts, Clark A. 1985. Availability of federally owned minerals for exploration and development in western states: Colorado, 1984. Washington, D.C.: USDI, Bureau of Mines Special Report 3-85. 40 p.

Berger, Bill D.; Anderson, Kenneth E. 1992. Modern Petroleum. PennWell Books, Tulsa, OK. 517 p.

Blackgoat, Fernando, Exxon Corporation. August 10, 1992. Personal communication.

Bohi, D.R. 1981. Analyzing demand behavior: a study of energy elasticity. Quoted in: Hartwick, John M.; Oleweiler, Nancy D. 1986. The economics of natural resource use. NY: Harper and Row. pp. 224-228.

Bottge, R.G.; Northan, M.J. 1986. Availability of land for mineral exploration and development in south-central Alaska, 1985. Washington, D.C.: USDI, Bureau of Mines Special Report 3-87. 45 p.

Bottge, R.G. 1986. Availability of land for mineral exploration and development in north-central Alaska, 1985. Washington, D.C.: USDI, Bureau of Mines Special Report 2-87. 37 p.

Bottge, R.G. 1988. Availability of land for mineral exploration and development in western alaska, 1986. Washington, D.C.: USDI, Bureau of Mines Special Publication 2-89. 47 p.

Boyle Jr., E.H.;Shields, D.J.;Wagner, L.A. 1992. Chromium availability in market economy countries and network flow model analysis of world chromium supply. Washington, D.C.: USDI, Bureau of Mines. 323 pp.

Buckner, Michael. July 5, 1994. United Mine Workers of America. Washington, D.C. Personal communication.

Buthod, Paul. 1962. Properties of crude oils and liquid condensate. In: Frick, Thomas C.; Taylor, R. William. (eds.) Petroleum production handbook. Dallas, TX: Society of Petroleum Engineers of AIME. pp. 18-1 - 18-23.

Campbell, Gary. 1985. Theory of mineral demand. In:Vogely, William (ed.) Economics of the mineral industries.

ed. NY: American Institute of Mining, Metallurgical, and Petroleum Engineers: 161-180.

Caruccio, F.T.; Hossner, L.R.; Geidel, G. 1988. Pyritic materials: acid drainage, soil acidity and lining. In: Hossner, L.R., ed. Reclamations of Surface Mined Lands. Boca Raton, FL: CRC Press: 159-190. Vol. 1.

Chamberlain, Peter; Stewart, William O. 1992. Mining technology for the 21st century. In: Mañana, R., ed. dir. mining outlook: Proceedings of the XV World Mining Congress; 1992 May 25-29; Madrid, Spain: World Mining Congress: 1:35-42.

City and Borough of Juneau, Alaska. 1989. Ordinance of the City and Borough of Juneau, Serial No. 89-47am.

Crandell, W.D.;Hamilton, M.M. 1991. Availability of federally owned minerals for exploration and development western states: Nevada 1985. Washington, D.C.: USDI, Bureau of Mines Special Publication 2-91. 54 p.

Cremer, Jacques, and Djavad Salehi-Isfahani. 1991. Models of the Oil Market. Harwood Academic, NY. 106 p.

Crowson, Phillip. 1988. A perspective on worldwide exploration for minerals. In: World Mineral Exploration. Tilton, J.E.; Eggert. R.G.; and H.H. Landsberg (eds.) Resources for the Future, Washington, D.C. pp. 21-104.

Dean, K.C.; Shirts, M.B. 1977. Vegetation for acidic and alkaline tailings. In: Thames, J.L., ed. Reclamation and of disturbed land in the Southwest. Tucson, AZ: University of Arizona Press: 248-261.

DeVilbiss, John M. 1992. Economic diversity & dependency assessment. Denver, CO: USDA, Forest Service, Rocky Mountain Region. 6 p.

Dimatteo, E. 1992. Colorado Oil and Gas Conservation Commission. Personal communication.

Difrancesco, C.A.;Cornellisson, J.L.;Peterson, G.R. 1992. The Availability of primary lead and zinc in market economy countries, a minerals availability appraisal. Washington, D.C.: USDI, Bureau of Mines. 62 p.

Dorr, A. 1987. Minerals: Foundations of society. American Geological Institute, Alexandria, Va.

Economic Report of the President. 1992. Washington, D.C.: U.S. Government Printing Office. 423 p.

Eichmeyer, H.; Wilke, F.L. 1992. Underground disposal and underground utilization of waste and residues as a contribution to active environmental protection. In: Mañana, R., ed. dir. 1992. The mining outlook: Proceedings of the XV World Mining Congress; 1992 May 25-29; Madrid, Spain: World Mining Congress: 1: 957-966.

Evans, Barbara. 1984. Mine capacity utilization during recessionary periods: operating strategy in the domestic copper industry. Stanford, CA: Stanford University. 236 p. PhD. Dissertation.

Fantel, Richard; Hurdelbrink, Ronald; Shields, Deborah; Johnson, Ralph. 1988. Phosphate availability and supply. Information Circular 9187. Washington, D.C.: U.S.D.I. Bureau of Mines. 70 p.

Fantel, Richard. September 4, 1993. USDI, Bureau of Mines. Personal communication.

Feltweis, Gunter B. 1979. World coal resources: methods of assessment and results. Developments in Economic Geology. 10: 191-227.

Fogg, C.T.;Cornellisson, J.L. 1992. Availability of platinum and platinum-group metals. Washington, D.C.: USDI,

Bureau of Mines. 113pp.

Frick, Thomas C.; Taylor, R. William (eds.). 1962. Petroleum production handbook, Vol. II. Dallas, TX: Society Petroleum Engineers of AIME.

Fuentes-Cantillana, J.L.; Catalina, J.C.; Rodriguez, A. 1992. Robotization of a roadheader in a selective cutting operation. In: In: Mañana, R., ed. dir. The mining outlook: Proceedings of the XV World Mining Congress; 1992 May 25-29; Madrid, Spain: World Mining Congress: 1:175-182.

Gilbert, Richard; Harris, Richard. 1984. Competition with lumpy investment. Rand Journal of Economics. 15(2):197-212.

Gray, A. W., et al. 1989. Availability of federally owned minerals for exploration and development in western states: New Mexico, 1987. Washington, D.C.: USDI, Bureau of Mines Special Publication 5-89. 32 p.

Griffin, James; Steele, Henry. 1986. Energy Economics and Policy. Academic Press, Orlando, Fl. 398 p.

Hamm, Eduard. 1992. New methods of underground cavity filling for reduction of subsidence and for disposal of wastes. In: Mañana, R., ed. dir. 1992. The mining outlook: Proceedings of the XV World Mining Congress; 1992 May 25-29; Madrid, Spain: World Mining Congress: 1: 1011-1020.

Hartwick, John. 1989. Non-renewable resources extraction programs and markets. NY: Harwood Academic. 150 p

Hodges, C.A. 1995. Mineral resources, environmental issues, and land use. Science. 268: 1305-1312.

Hutchison, I.P.G.; Ellison, R.D. 1992. Mine Waste Management: a resource for mining industry professionals, regulators and consulting engineers. Chelsea, MI: Lewis Publishers.

Hyndman P.C., et al. 1992. Availability of federally owned minerals for exploration and development in western states: Idaho, 1988. Washington, D.C.: USDI, Bureau of Mines Special Publication 1-92. 56 p.

International Lead and Zinc Study Group (ILZSG). Lead and Zinc Statistics. Monthly Bulletins.

International Lead and Zinc Study Group (ILZSG). April 1989. Trends and Consumption of Lead and Zinc.

Jansen, I.J.; Melsted, S.W. 1988. Land shaping and soil construction. In: Hossner, L.R., ed. Reclamations of Surface Mined Lands. Boca Raton, FL: CRC Press: 125-136. Vol. 1.

Jevons, W.S. 1906. The coal question. 3rd e. London: MacMillian. 20 p.

Johnson, W.; Paone, J. 1982. Land utilization and reclamation in the mining industry, 1930-80. Information Circular 8862. Washington, D.C.: USDI, Bureau of Mines. 22 p.

Johnson, Robert. 1992. Producers of natural gas face dilemma as prices hit new lows. The Wall Street Journal. January 27; Section C:1.

Johnston, P.R.; Durucan, S.; Owen, D.B. 1993. The application of a geographical information system to environmental impact assessment in the minerals industry. In: Elbrond, Jorgen; Tang, Xiaoli (eds.) Proceedings of the XXIVth International Symposium on the Application of Computers and Operations Research in the Mineral Industries. October 31-November 3, 1993, Montreal, Quebec, Canada. Montreal: APCOM. pp. 513-520.

Kinkel, Robert A.;Smith, Roderick C. 1991. Gold situation 1991. Lakewood, CO: Metal Market Consultants. 162 p.

Kotliar, N.B.; Wiens, J.A. 1990. Multiple scales of patchiness and patch structure: a hierarchical framework for study of heterogeneity. Oikos. 59: 253-260.

Landefeld, J. Steven; Hines, James R. 1985. National accounting for non-renewable natural resources in the mining industries. Review of income and wealth. 31(1): 1-20.

Langer, W.H. 1988. Natural aggregates of the conterminous United States. Washington, D.C.: USDI, Geological Survey Bulletin 1594. 33 p.

Lasserre, Pierre. 1991. Long term control of exhaustible resources. Reading, PA: Harwood Academics. 122 p.

LLewelwyn, John, 1983. Resource prices and macroeconomic policies. O.E.C.D. Economic Studies. 1: 198-212.

Longwill, W.D. 1988. Availability of federally owned minerals for exploration and development in western states: Oregon, 1984. Washington, D.C.: USDI, Bureau of Mines Special Publication 4-88. 27pp.

Lynd, Langtry E. 1980. Titanium. In: Mineral facts and problems. Bull.671. Washington, D.C.: U.S.D.I., Bureau of Mines: 961-978.

Mass, K.M. 1987. Availability of land for mineral exploration and development in northern alaska 1986. Washington, D.C.: USDI, Bureau of Mines Special Publication 4-87. 34 p.

Mass, K.M. 1988. Availabiity of land for mineral exploration and development in southwestern Alaska, 1986. Washingotn, D.C.: USDI, Bureau of Mines Special Publication 1-89. 35 p.

Mast, R.F.; Dolton, G.L.; Crovelli, R.A.; Root, D.H.; (et al). 1989. Estimates of undiscovered conventional oil and gas resources in the United States - a part of the Nation's energy endowment. USDI, Geological Survey and Minerals Management Service. Washington, D.C. 44 p.

Matthey PLC, Johnson. 1991. Platinum 1991. NY: Donley Communications. 64 p.

McColly, R.A.; Anderson, Neal B. 1987. Availability of federally owned minerals for exploration and development in western states: Arizona, 1986. Washington, D.C.: USDI, Bureau of Mines Special Publication 5-87. 27 p.

McDivitt, James F.; Manners, Gerald. 1974. Minerals and men. Baltimore, MD: Johns Hopkins Press for Resources for the Future. 173 p.

McElfish, J.M.; Beier, A.E. 1990. Environmental regulation of coal mining: SMCRAS Second Decade. Washington, DC: Environmental Law Institute.

Meadows, Donella H.; Meadows, Dennis L.; Randers, Jorgen; Behrens III, William W. 1972. The limits to growth: a report for the Club of Rome's Project on the predicament of mankind. NY: Universe Books. 207 p.

Medici, M. 1974. The Natural Gas Industry. Newnes-Butterworths, London. 356 p.

Metal Market Consultants, Inc. 1990. Gold situation 1990. Lakewood, CO.

Miernyk, William H. 1965. The elements of input-output analysis. NY: Random House. 156 p.

Miller, R.M.; Cameron, R.E. 1976. Some effects on soil microbiota of topsoil storage during surface mining. In: Proceedings of 4th Symposium on Surface Mining and Reclamation; 1976 Oct 19-21; Louisville, KY: National Coal Association: 131-135.

Mining Journal. 1990. Traumatic year for uranium. 314(8060):176.

Mitchell, C.J., Viceroy Gold Corporation. October 21, 1992. Personal communication.

Montana Department of State Lands et al. 1992. Final environmental impact statement-Stillwater Mine expansion 2000 TPD. Helena, MT: State of Montana. 92 p.

Myers, John G.; Barnett, Harold J. 1985. Minerals and economic growth. In: Vogely, William (ed.) Economics of the Mineral Industries, 4th Edition. American Institute of Mining, Metallurgy, and Petroleum Engineers, Inc., NY. pp. 3-17.

National Coal Association. 1991. Facts about coal. Washington, D.C. 100 p.

National Coal Association. 1993. Facts about coal. Washington, D.C. 100 p.

National Research Council. 1979. Surface mining of non-coal minerals. Washington, DC: National Academy of Sciences.

Newendorp. Paul D. 1975. Decision analysis for petroleum exploration. Tulsa, OK: PennWell Books. 668 p.

Nordhaus, William D. 1973. The allocation of energy resources. Brookings Papers on Economic Activity. 3:529-576.

Nordhaus, William D. 1980. Oil and economic performance in industrial countries. Brookings papers on Economic Activity. 2: 3441-399.

Oak Ridge Associated Universities. 1979. Determinates of coal mine labor productivity change. Washington, D.C.: USDOE and USDOL. 25 p.

Palencia, C.M. 1985. Molybdenum availability-market economy countries, a minerals availability appraisal. Washington, D.C.: USDI, Bureau of Mines I.C. 9044. 30 p.

Paone, J.; Struthers, P.; Johnson, W. 1978. Extent of disturbed lands and major reclamation problems in the U.S. In Schuller, F.W.; Sutton, P. Reclamation of drastically disturbed lands. Am. Soc. of Agron. Madison, WI. pp. 11-22.

Peer Consultants. 1984. Assessment of the effects on soils and waters due to anticipated coal development in the United States. Washington, D.C.: USDA, Forest Service.

Perry, A.; Kleinman, R. 1992. Constructed wetlands for the treatment of acid mine drainage in the United States. In Mañana, R., ed. dir. 1992. The mining outlook: Proceedings of the XV World Mining Congress; 1992 May 25-29; Madrid, Spain: World Mining Congress: 1: 1093-1100.

Petroleum Extension Service. 1981. Fundamentals of Petroleum. The University of Texas at Austin, Austin, TX. p.

Plummer, A.P. 1977. Revegetation of disturbed intermountain area sites. In: Thames, J.L., ed. Reclamation and of disturbed land in the Southwest. Tucson, AZ: University of Arizona Press: 302-339.

Porter, K.E.; Peterson, G.R. 1992. The availability of primary copper in market economy countries, a minerals availability appraisal. Washington, D.C.: USDI, Bureau of Mines I.C. 9310. 26 p.

Proctor, Raymond. 1992. Opencast mining and the environment. In: Mañana, R., ed. dir. 1992. The mining outlook: Proceedings of the XV World Mining Congress; 1992 May 25-29; Madrid, Spain: World Mining Congress: 1: 1101-1107.

Prugger, Fritz F. 1992. Backfill as a means to make mining more environment friendly. In: Mañana, R., ed. dir. 1992. The mining outlook: Proceedings of the XV World Mining Congress; 1992 May 25-29; Madrid, Spain: World Mining Congress: 1: 1111-1120.

Radetski, Marian: Tilton, John E. 1990. Conceptual and methodological issues. In. Tilton, John E. (ed.) World metal demand: trends and prospects. Washington, D.C.: Johns Hopkins Press for Resources for the Future. 13-34.

Raghavan, Anita. 1992. Platinum futures prices tumble after report of new diesel converters that use palladium. Wall Street Journal. July 22; Sect. C:14.

Randall, Alan. 1981. Resource economics. Grid Publishing, Columbus, OH. 415 p.

Rees, Judith. 1985. Natural resources: allocation, economics, and policy. NY: Routledge. 499 p.

Reisinger, Robert. November 30, 1993. USDI, Bureau of Mines. Personal communication.

Reith, Charles C. 1986. Introduction and overview of methods in reclamation science. In: Reith, Charles C.; Potter, Loren D. (eds.) Principles and methods of reclamation science. Albuquerque, NM: University of New Mexico Press. pp. 1-16.

Rightmire, Craig T.; Eddy, Greg E.; Kirr, James N. 1984. Coalbed methane resources of the United States. Tulsa, OK: American Association of Petroleum Geologists. 378 p.

Roberts, Mark. 1990. Predicting metal consumption. Resources Policy. March:56-93.

Roberts. W.S. 1985. Availability of land for mineral exploration and development in southeastern Alaska, 1984. Washingotn, D.C.: USDI, Bureau of Mines Special Publication 1-85. 34 p.

Slade, Margaret. 1989. The two pricing systems for non-ferrous metals. Resources Policy. Sept.:209-215.

Sparrow, F.Thomas; Soyster, A. 1980. Process models of minerals industries. In: Proceedings of the 109th annual meeting of American Institute of Mining, Metallurgical, and Petroleum Refiners. 1980 February 24; Las Vegas, NV. NY: American Institute of Mining, Metallurgical, and Petroleum Engineers.: 93-101.

Solow, Robert M. 1986. On the intergenerational allocation of natural resources. Scandinavian Journal of Economics 88(1):141-149.

Tilton, John. 1986. Beyond intensity of use. Materials and Society. 10(3):245-250.

Tilton, John, (ed.) 1991. Mineral wealth and economic development. Washington, D.C.: Johns Hopkins Press for Resources for the Future. 121 p.

Toman, Michael A. 1993. The economics of energy security: theory, evidence, and policy. In: Handbook of natural resource and energy economics, Vol. III. NY: Elsivier. pp. 1167-1218.

US Congress. 1990. Abandoned Mine Reclamation Program. Hearings; 1989 May 16; Washington, DC: U.S. Govt. Printing Office.

US Congress, Office of Technology Assessment. February 1988. Oil production in the Arctic national wildlife refuge: the technology & the Alaskan oil context. 123 p.

USDA, Forest Service. 1985. Mining in the national forests. Current Information Report 14. Washington, D.C. 8 p.

USDA, Forest Service. 1989. Basic assumptions: a technical document supporting the 1989 USDA Forest Service RPA assessment. General Technical Report RM-174. Ft. Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 11 p.

USDA, Forest Service. 1993. ASCII Database of Economic Diversity Indices.

USDA, Forest Service. 1995. Anatomy of a mine from prospect to production. Gen. Tech. Rep. INT-GTR-35. Ogden, UT: USDA, Forest Service, Intermountain Forest and Range Experiment Station. 69 p.

USDOC, Bureau of Economic Analysis. 1995.

USDOC, Bureau of the Census. 1974. Census of Mineral Industries 1972. Washington, D.C.: U.S. Government Printing Office. 40 p. + appendices.

USDOC, Bureau of the Census. 1979. Census of Mineral Industries 1977. Washington, D.C.: U.S. Government Printing Office. 44 p. + appendices.

USDOC, Bureau of the Census. 1984. Census of Mineral Industries 1982. Washington, D.C.: U.S. Government Printing Office. 44 p. + appendices.

USDOC, Bureau of the Census. 1989. Census of Mineral Industries 1987. Washington, D.C.: U.S. Government Printing Office. 44 p. + appendices.

USDOC, International Trade Administration; USDI, Bureau of Mines. 1988. A cost comparison of selected U.S. a Canadian coal mines. Washington, D.C.: USDI, Bureau of Mines. 65 p. + appendices.

USDOC, International Trade Administration; USDI, Bureau of Mines. 1989. A cost comparison of selected U.S. a Australian coal mines. Washington, D.C.: USDI, Bureau of Mines. 92 p. + appendices.

USDOC, International Trade Administration; USDI, Bureau of Mines. 1990. A cost comparison of selected U.S. a South African coal mines. Washington, D.C.: USDI, Bureau of Mines. 131 p.

USDOC, National Technical Information Service. 1992. Annual energy review database 1991 (for microcomputers). Washington, D.C.: NTIS Federal Computer Products Center. Two 5 1/4 inch diskettes, 1.2 M

high density.

USDOC, Bureau of Economic Analysis. 1993. Regional economic information system (on CD-ROM). Washington, D.C.: DOC.

USDOE, 1992. Integrated Analysis Supporting the National Energy Strategy: methodology, assumptions and results. Technical Annex 2. DOE/s-0086P. USDOE, Washington, D.C. 170 p.

USDOE, EIA. 1990. The domestic oil and gas recoverable resource base: supporting analysis for the national energy strategy. SR/NES/90-05. Washington, D.C.: DOE, EIA.

USDOE, EIA. 1991. Annual prospects for world coal trade 1991. DOE/EIA-0363(91). Washington, D.C.: DOE, EIA. 129 p.

USDOE, EIA. 1992. The U.S. coal industry, 1970-1990: two decades of change. DOE/EIA-0559. Washington, D.C.: U.S. Government Printing Office. 105 p.

USDOE, EIA. 1993a. The U.S. petroleum industry: past as prologue 1970-1992. DOE/EIA-0572. Washington, D.C: U.S. Government Printing Office. 70 p.

USDOE, EIA. 1993b. Annual Energy Outlook. DOE/EIA-0383 (93). Washington, D.C.: DOE, EIA. 214 p.

USDOE, EIA. 1993c. Annual energy review 1992. DOE/EIA-0384(93). Washington, D.C.: U.S. Government Printing Office. 383 p.

USDOE, EIA. 1993d. Coal production 1992. DOE/EIA-0118(92). Washington, D.C. 113 pp.

USDOE, EIA. 1994. Annual energy review 1993. DOE/EIA-0384(93). Washington, D.C.: U.S. Government Printing Office. 383 p.

USDI, Bureau of Land Management. 1980. Buffalo resource area: oil and gas environmental assessment. Casper District, Wyoming.

USDI, Bureau of Land Management and U.S. Forest Service. 1989. Oil and gas: surface operating standards for and gas exploration and development. Lakewood, CO: BLM/FS Rocky Mountain Regional Coordinating Committee.

USDI, Bureau of Land Management. 1990. Castle Mountain Project: San Bernardino County, California. Final EIS/EIR.

USDI, Bureau of Land Management. 1992. Solid Minerals Reclamation Handbook. BLM Manual Handbook H-3042-1. Washington, DC: U.S. Department of the Interior.

USDI, Bureau of Land Management. 1994. Public land statistics 1993. Washington, D.C.: USDI, Bureau of Land Management. 143 p.

USDI, Bureau of Mines. 1936. Bulletin 390. Washington, D.C. p. 3.

USDI, Bureau of Mines. 1960-1989. Minerals Yearbook, Vol.1. Washington, D.C.: U.S. Government Printing

Office.

USDI, Bureau of Mines. 1975. Mineral facts and problems, 1975 Edition. USBM Bulletin 667. Washington, D.C.: U.S.Government Printing Office. 1259pp.

USDI, Bureau of Mines. 1980. Mineral facts and problems, 1980 Edition. USBM Bulletin 671. Washington, D.C.: U.S.Government Printing Office. 1060pp.

USDI, Bureau of Mines. 1983. Mineral commodity summaries. Washington. D.C.: U.S. Governmental Printing Office. 183 p.

USDI, Bureau of Mines. 1985. Mineral facts and problems, 1985 Edition. USBM Bulletin 675. Washington, D.C.: UlSlGovernment Printing Office. 956pp.

USDI, Bureau of Mines. 1986. Mineral commodity summaries. Washington. D.C.: U.S. Governmental Printing Office. 187 p.

USDI, Bureau of Mines. April 10, 1987. Mineral industry surveys, ferrous metals supply/demand data, 1975-1985. Washington, D.C.: U.S. Government Printing Office. 29 p.

USDI, Bureau of Mines. 1987. The Mineral Position of the United States--1987. Annual Report of the Secretary the Interior Under the Mining and Minerals Policy Act.

U.S. Bureau of Mines. 1987. Mineral industry surveys, nonferrous metals supply/demand Data, 1975-1985. Washington, D.C.: U.S. Government Printing Office. 64 p.

USDI, Bureau of Mines. June 22, 1987. Mineral industry surveys, industrial minerals supply/demand data, 1975-1985. Washington, D.C: U.S. Government Printing Office. 85pp.

USDI, Bureau of Mines. 1988. Mineral commodity summaries. Washington. D.C.: U.S. Governmental Printing Office. 192 p.

USDI, Bureau of Mines. 1989. Mineral commodity summaries. Washington. D.C.: U.S. Governmental Printing Office. 191 p.

USDI, Bureau of Mines. 1990. Mineral commodity summaries. Washington. D.C.: U.S. Governmental Printing Office. 199 p.

USDI, Bureau of Mines. 1991a. The new materials society, Vol. 3. Washington, D.C. pp. 1.10-1.11.

USDI, Bureau of Mines. 1991b. Constructed wetlands reduce cost of treating coal mine drainage. Technology Transfer Announcement. Washington, D.C.: Bureau of Mines. 27 p.

USDI, Bureau of Mines. 1991c. Mineral commodity summaries. Washington. D.C.: U.S. Governmental Printing Office. 196 p.

USDI, Bureau of Mines. 1992. Mineral commodity summaries. Washington. D.C.: U.S. Governmental Printing Office. 204 p.

USDI, Bureau of Mines. 1993. Mineral commodity summaries. Washington. D.C.: U.S. Governmental Printing Office. 202 p.

USDI, Bureau of Mines. 1995. Mineral commodity summaries. Washington. D.C.: U.S. Governmental Printing

Office. 202 p.

USDI, Geological Survey. 1983. Reclamation of mined lands in the Western coal region. Geol. Survey Circ. 872.

USDOL, Bureau of Labor Statistics. 1984. Supplement to employment and Earnings. Washington, D.C.: DOL,BLS.

USDOL, Bureau of Labor Statistics. 1989. Supplement to employment and Earnings. Washington, D.C.: DOL,BLS.

USDOL, Bureau of Labor Statistics. 1991. Supplement to employment and Earnings. Washington, D.C.: DOL,BLS.

USDOL, Bureau of Labor Statistics. 1993. Employment and earnings. Vol. 40, No. 9. Washington, D.C.: DOL. 9 p.

USDOL, Bureau of Labor Statistics. 1995. Stats.bls.gov. via internet. Washington, D.C.: USDOL, BLS.

US Environmental Protection Agency. 1985. Report to Congress: wastes from the extraction and beneficiation of metallic ores, phosphate rock, asbestos, overburden from uranium mining, and oil shale. 285 p.

USGAO, Comptroller General. 1981. Low productivity in american coal mining: causes and cures. GAO EMD- 81-7. Washington, D.C.: GAO.

WEFA Group. 1992. World Demand for Fertilizer Nutrients for Agriculture. Report prepared for the U.S. Bureau of Mines. 53 p.

Wenner, Lambert N.1992. Minerals, people and dollars: social, economic and technological aspects of mineral resource development. Missoula, MT: USDA, Forest Service, Northern Region, R1-92-133. pp. 86-87.

White, Lane; Kral, Steve. 1994 Barrick Gold. Mining Engineering. 46(11): 1231-1242.

World Commission on Environment and Development. 1987. Our common future. Oxford: Oxford University Press. 383 p.

Zimmerman, E.W. 1951. World resources and industries. rev. edn. NY: Harper.

The physical and economic availability of mineral and energy resources is an extremely important aspect of assessing the resources of the U.S. Forest System's lands. Many different topics affect this analysis, including the nature and characteristics of the resources and the industries that process these resources, the economic climate surrounding resource production and trade, and governmental activities that relate to the environmental impacts of resource production and use. In analyzing the effects from these topics, this report will examine impacts at international, national, regional, and forest-level scales since activities dealing with USFS-derived mineral and energy resources usually take place outside the boundaries of Forest Service lands.

THE NATURE OF EXHAUSTIBLE RESOURCES

Nonrenewability is an important characteristic of metals, industrial minerals, petroleum, natural gas, and coal. These are scarce resources that cannot be created in any meaningful time frame. Scarcity can be defined both physically and economically. The quantity of mineral and energy resources on earth is theoretically finite so in this sense there is a physical upper limit to the amount that can eventually be extracted. Some materials are nearly ubiquitous in the earth's crust and could supply human needs for the indefinite future. From an economic standpoint, however, mineral and energy resources have a much tighter limit. One view says that the cost of extraction should rise over time as accessible deposits are mined and extraction becomes more difficult. Eventually the costs should reach a point where further extraction is not beneficial and the resource becomes "economically" exhausted. Another view stresses the importance of technical progress, which should ease extraction costs over time as we find way to access more remote deposits. In addition, substitution of other forms of capital (human, renewable, and man-made) can offset the economic need for exhaustible resource capital. This economic aspect of scarcity requires that industry decision-making regarding extraction must account for inter-temporal effects from current levels of mining. The rate of resource development on public lands often a function of the relative scarcity of mineral and energy resources.

Other characteristics include the quality of the resource and the inherent risk of exploration and development. Variability depends on the specific resource in question. Metallic minerals are often subject to so much processing that the resultant product is homogenous from one source to another. At the other

extreme, coal and phosphate are resources that have a wide range in qualities. Obviously, firms will be more willing to explore and mine where the quality of the resource is likely to be high. Uncertainty in terms of both the success of exploration and production profitability is a main determinant in the type of firm that chooses to develop a given deposit – small firms often are more willing to explore questionable deposits, and larger firms usually a bit more conservative.

These characteristics of exhaustible resources shape the economic structure of mineral and energy industries. The basic determinant of how the market for these resources operates is the interaction between the supply and demand. Many products contained today include some form of mineral resources and are usually produced with some form hydrocarbon energy source. Thus, the demand for mineral and energy resources is really derived from the demand for some other products. Demand for these resources is a flow measure that is impacted by the traditional determinants of economic demand: selling price, prices of other related goods, and income. The latter variable is an especially important determinant as can be seen in the cyclical pattern of resource use over time depending on how a variety of events affect national and global income level. Trends in material use and substitution among materials also determine the demand for mineral and energy resources. Sometimes, technological improvements favor a specific mineral resource, and at other times production processes might favor alternative material or energy resources such as polymers and renewable resources.

Along with demand, mineral and energy resource supply determines the level of development and extraction over time. Measured as a stock variable, the quantity of supply can be represented with its resource base and with the mineral's reserves. However, measuring supply as a flow variable allows an easier comparison with resource demand in assessing the economic outlook. Capacity, production, inventories, and trade are often used to report supply. These flow measures vary in usefulness depending on whether one is analyzing historical situations or forecast trends. The technologies available in the extraction and processing industries are an important determinant in resource supply. Tradeoffs between the high cost of new capital technology and its relative productivity have impacts on the exploration and development decisions undertaken by a given firms. In addition, requirements to control adverse environmental effects and/or reclaim mines can lead companies to restrict overall supply or utilize technologies that limit these adverse impacts.

Production and use of energy and mineral resources affect not only the resource industries, but also influence regional and national economic vitality. Although the overall contribution of these industries to national income has historically been quite low and declining, most other industries rely on the ready availability of resource production. Any significant disruption could have tremendous economic impacts. Resource industry influence is even stronger at the local and regional level. Some states such as Wyoming and Alaska and especially many local communities are entirely dependent on extractive industries in terms of employment and tax base. Also, for a few minerals, the United States is the dominant supplier for the international commodity market.

The extraction, processing, and use of energy and mineral resources is inextricably linked with the natural environment. Polluting effects can result from the accidental (or intentional) discharge of contaminants into the surrounding ecosystem, including the air, soil and water. Specific environmental impacts also depend on the local climate and surrounding ecosystem. Areas with more rainfall and wetlands are usually more susceptible to the effects of pollution. In addition, exploration activities are generally less damaging than the development stage due to the smaller scale and shorter time horizon involved.

Federal legislation has been enacted over the last few decades in an attempt to mitigate these environmental effects from mining and energy extraction. These laws have provided a minimum level of environmental safeguards, acting as a backup to state and local laws. One of the most relevant laws relating to the exploration and development of resource deposits is the National Environmental Policy Act (NEPA). This law requires preparation of an Environmental Impact Statement or Environmental Assessment (depending on the significance of the impact) for any project that takes place on federal land. Such documents create awareness on the part of all stakeholders as to the possibility of adverse environmental consequences, and ensure that these impacts are properly mitigated. Other legislation such as the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) work to require mining and energy producers to properly account for and clean up hazardous wastes.

INDICATOR RESOURCES OVERVIEW

Information regarding the consumption, production and availability of important commodity resources provides a foundation for an effective assessment of these resources on forest service lands. This document focuses on ten mineral indicator resources (chromium, copper, construction sand & gravel, crushed stone, gold, lead, molybdenum, phosphate rock, platinum group metals, and zinc) and the hydrocarbon resources (petroleum, natural gas, and coal).

Chromium is used in the production of stainless steel. This consumption is expected to grow approximately 3% annually for the foreseeable future. Demand in the United States is satisfied solely by imports, mainly from South Africa. The largest chromium resource location in the U.S. is the Stillwater complex in Montana. However, no reserves are available to economically mine given current technology and market prices. Molybdenum is another industrial metal that is primarily used as an alloy for steel. The U.S. has the world's largest reserve base and is a major producer although there are only two primary producers. Development of the Quartz Hill deposit in the Tongass National Forest of Alaska has been controversial due to potential waste dumps into nearby fjords.

Copper metal has many industrial uses due to its desirable physical properties. Its use in the electrical industry has generated much growth in consumption over the last few decades, although that growth has slowed slightly in recent years with the advent of fiber optic cable for telecommunications. U.S. demand is forecasted to increase 2.9% over the next few decades. Although the United States has the world's second largest reserves of copper, production in South America and other locations has expanded recently, and U.S. imports increased dramatically in the late 1990's. Heap leaching of copper ores is becoming more widely used in copper mines worldwide, and the industry has taken a proactive stance towards potential environmental problems by properly designing mining facilities. Large, undeveloped copper deposits occur on NFS lands, but many are located in areas restricted from mineral development.

Non-metallic industrial minerals include construction sand & gravel, crushed stone and phosphate rock. Sand & gravel and crushed stone are one of the most available natural resources and are considered high volume, low value commodities. Both resources have been heavily used in the construction of roadways, and consumption has risen rapidly since the 1980's. They are produced at thousands of mines

across the United States. Generally, suppliers need to be located close to urban markets due to high transportation costs. Environmental problems include air and noise pollution from processing of gravel and crushed stone. Forest service lands have abundant resources, but they account for a very small percentage of production due to the distant from markets.

Phosphate rock is heavily used in the fertilizer industry. Demand for this resource is derived from consumption of food, primarily in grain products. Reduced planted acreage and large inventories of grain have stifled U.S. demand for phosphate rock in recent years. This trend is expected to continue for another decade or so, then consumption is forecast to grow at 0.5% annually. The U.S. is one of the largest producers and exports a great deal of its production. Worldwide demand are projected to rise over 3% annually through 2005, so exports should likewise increase. Mining of this resource occurs in the Southern states, especially Florida, and in Idaho and Utah. Deposits have been discovered in the Osceola and Caribou National Forests, however lease applications to mine these areas has been denied due to effects on local aquifers.

The two precious or noble metals discussed in the assessment are gold and the platinum group metals (PGM). Both metals are used extensively in the jewelry and arts industry. The largest demand sector for platinum group metals is for catalysts in automobiles. This use has significantly increased the growth rate of PGM since the 1980's. Another potential source of rapid growth is the application of platinum in fuel cell technology. The upward trend in PGM consumption is expected to continue at 2.8% annually. Growth in gold consumption for industry and the arts should rise 2% per year over the next few decades. Gold was extensively mined in the U.S. during the nineteen and early twentieth centuries, but production fell through the 1970's. Production has increased since then, generally in the form of large open-pit mining operations accounting for about 12% of world production. More than 90% of the world's PGM production is mined in South Africa and Russia. The Stillwater complex in the Custer National Forest of Montana is the only currently producing primary PGM mine within the United States. Interest has been expressed in developing a cyanide leaching facility in the Gallatin National Forest to extract gold, however the application is pending. Although an effective method of treating ore, cyanide leaching has also resulted in a few environmental accidents in recent years.

Lead and zinc are two minerals that have many commonalities, especially their corrosion resistance. The major end-use of lead is the manufacture of lead-acid batteries while zinc is used in a variety of industrial applications, mainly as a galvanizing coating to prevent corrosion or as an alloying metal. In the early 1980's lead consumption fell because of environmental regulations that significantly reduced the use of lead in products such as gasoline and paints. During the 1990's, demand began to rise once more with an increased use of both storage and industrial-type batteries. This growth is forecasted to continue into the future albeit at a slower rate of about 1% annually. Growth in U.S. zinc consumption is expected to be about 1.2%; world demand may exceed this rate of growth as less-developed countries see their incomes rise. Lead and zinc are often mined together as coproducts, usually in underground mines. Processing of lead can sometimes generate toxic airborne lead dust. Zinc and lead ores are not a threat to human health, but the potential for acid mine drainage exists from waste piles. This is one of the reasons that attempts to explore and develop in the Mark Twain National Forest (the most productive source of lead in the U.S.) have been delayed.

Concern regarding security of supply for many of the minerals discussed above led to the creation of the National Defense Stockpile. However, there is now little need to maintain extensive stockpiles in the global marketplace of the post-Cold War era so most of these materials are being disposed of. The treasury department continues to hold stocks of gold bullion from the time when currency was tied to the gold standard. Copper stockpiles no longer exist, and those of most other minerals should disappear by 2005. The disposal of the stockpiles and variation in private industry inventories can have substantial impacts on mineral market conditions.

The United States is a major consumer of energy. Petroleum has been our most important source of fuel since 1950, due in large part to its importance as a transportation energy source. Per capita petroleum in the early 1970's and as a percentage of real GDP has continually declined since then. Much of this is a long-run reaction to the market distortions caused by the Arab embargo of 1973. However, per capita consumption has remained relatively constant since 1980, reflecting the price inelasticity of petroleum. Likewise, U.S. production of crude oil peaked in 1970 and our share of world production has steadily declined over this period. Net imports briefly declined after 1980, but since 1985 have risen continuously. Around 50% of total crude oil and its resulting products that are supplied within the U.S. are

imported from abroad. Reserves of petroleum within the U.S. represent only 3.2% of those in the Middle East and only 2.1% of those worldwide. Estimates of reserves may be revised upwards with improvements in technology. Although deposits in Alaska and the offshore Gulf of Mexico region show promise, U.S. petroleum consumption will likely continue to rely on global trade.

Another energy resource, natural gas, may become more widespread in the near future. Widely seen as less environmentally damaging than the other hydrocarbon resources, natural gas has been used more widely in new electrical power plants. Demand also arises from household heating needs. Rising climatic temperatures and improvements in insulation have reduced consumption from this sector. Demand for natural gas is generally more volatile than petroleum (in line with price fluctuations), because there are more substitute energy sources available. Imports have until recently accounted for only a small part of the natural gas market because of the high cost of long-distance transportation. There are economic reserves located in the Rocky Mountain states, the Colorado Plateau, and the Gulf Coast. Development of coal-bed methane has started to become more frequent recently.

Coal is the traditional source of hydrocarbon energy and saw its consumption rise with the Industrial Revolution of the 19th century. The vast majority of coal in the United States is used for power generation. Sulfur content is of concern due to the environmental effects of SO_2 discharged as emissions. Reserves of coal in the U.S. are concentrated in Appalachia, the South, and the Rocky Mountain states. Some major coal fields throughout the country encompass National Forest Service lands. The underground mining operations have resulted in land subsidence in some areas. The United States exports large amounts of coal, and even though U.S. consumption may decline in the future, demand from developing countries will likely result in increased production.

Federal lands, including the National Forest System (NFS), are underlain with extensive energy and mineral resources. Production on NFS lands for the three hydrocarbon energy indicator resources is forecasted to decline in the next few decades as development moves to other federal and private locations. Extraction of all the mineral indicator resources except molybdenum is expected to rise in the future although at a slower rate than the overall production growth rate.

This future pattern of resource extraction is only one potential impact on NFS lands. Abandoned and inactive mines also pose the potential for environmental problems. Unreclaimed sites can pose

physical hazards and often detract aesthetically from the landscape. Runoff from mining locations and waste piles can result in degraded water quality from acid mine drainage or other toxic discharges. Although responsibility for these problems should rest with the owners and operators of the facilities, it is often extremely difficult to track down the parties connected with the sites, especially for those abandoned sites that have sat dormant for decades. Therefore, the Federal and State governments have taken the initiative to safeguard hazards to many abandoned sites with the help of such programs as the Abandoned Mine Reclamation Fund.

OPPORTUNITIES FOR IMPROVED MANAGEMENT

Public land managers face many laws and regulations which often limit decision-making regarding mineral and energy resources. However, there are still opportunities for incorporating energy and mineral activities into planning. Information on background geology should be an integral part in the land planning process. This type of information can assist in ecosystem restoration, identification of potential hazards affecting health and safety, and contribute to the effective design and construction of NFS infrastructure.

Assessment of these resources can benefit land managers who seek to responsibly develop deposits on NFS lands. It may be appropriate to designate certain areas where mineral development will and will not be approved. Such actions could reduce industry uncertainty and provide local communities with accurate knowledge of how they should diversify their economies.

Incorporating minerals information can also prevent future conflicts. By knowing the location and extent of resource deposits, land planners can proactively compare potential land uses before commitment to a given designation may result in future controversy. Also, ownership of mineral claims with NFS lands need to be considered so the property rights will not be infringed.

The Forest Service's commitment to principles of ecosystem management require an assessment of the impact from mineral and energy resources. Development of these resources is needed for an effective national economy. Proper planning for mineral and energy activities, whether extraction or reclamation, can provide these necessary resource commodities while maintaining the integrity of the ecosystem.